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Dynamics of Human Societies: Narcissism

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The Generational Perspective

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Abstract

Human societies are incredibly complex. They consist of individuals who behave irrationally and erratically, guided by emotion rather than logic, taking influence from a myriad of internal and external stimuli. Their behaviours are so diverse, it is impossible to predict the society's evolution, even a short distance into the future.

And yet, from this supposèd anarchy we see global phenomena emerge. Cultures are formed which ebb and flow through society and time, social norms hold sway over the masses, and complex organisations are formed. In short, order emerges from chaos. Only through understanding the dynamics within a society can we hope to acquire knowledge of this second-order behaviour.

The study of human social interaction is therefore of vital importance. Global events are a culmination of individual interactions and their resultant chain-reactions. The effect of these interactions rely on the emotions and beliefs of the individuals involved, which are formed during childhood. The family environment is therefore a fundamental aspect of both individual and global behaviour. Celebrated psychologists throughout time - such as Freud, Kohut, and Jung - have all stated that relationships with parents during early childhood determines your essential character for life. Subsequently, to understand the system, it seems knowledge of the family dynamic is fundamental.

But how pervasive is the family's influence? A person's moral fiber is determined by the character of their parents, which is in turn dependent on the character of the grandparents…and so on. We see a chain reaction throughout time. But how long after a person has died will their past actions continue to affect future generations? And what is the effect on the state of society?

This paper presents a new framework for exploring these questions, in the form of a psycho-social model of a human society. It is a multi-agent abstraction of reality, simulating the family dynamic, and also narcissism: a psychological disorder. This is a very specific, and intriguing trait in itself. By modelling it accurately, it is possible to ascertain how it spreads through the generations, allowing a study of lineage memory. The main aims of this model are to test social hypotheses relating to narcissism, and also to gain valuable insight into the family's sphere of influence.

Acknowledgements

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I owe a debt of gratitude to Sandra Yarwood, who was always ready to discuss psychology with me, and also to Paul Bilokon, whose interest in my project was greatly valued. Finally, to my family and my best friends, thank you for everything. This could not have been done without you.

Contents

1. Introduction

1.1 The Science of Human Interaction

Sociology is an academic discipline on the study of society and human interaction. It ranges from the analysis of contact between anonymous individuals, to the study of global social processes; typically considering the complexities behind social organisation. It is a subject that has been under study from the times of Plato and Aristotle, and encompasses many areas of interest. These include social stratification, demography studies, criminology, politics and gender relations.

Through the use of theoretical frameworks, sociologists attempt to explain and analyse social action, and large-scale social structures. For example, three powerful social theories emerged from the 19th century relating to social and historical change: social cycle theory, social evolutionism, and Marxist historical materialism.

Many of these theories are subsequently deemed obsolete because of the continual change in society (consider the effect of the 60's on all pre-existing social structures), and also because of flaws in the premises. This is understandable, because the study of sociology relates directly to the vast complexity of human individuals.

The engagements and interactions between people are coloured by such a multitude of factors, that the response of any individual to a given situation can scarcely be determined. Consider a simple interaction such as buying an ice-cream at the beach: the precise nature behind the interaction is altered by previous interactions, gender and age considerations, the roles of the people involved (owner/customer), their emotional health, and a myriad of external factors like the weather.

In order to gain an understanding of local interaction, it is necessary to gain an understanding of the individual, and the factors which colour human encounters. Practically, this is done with a combination of quantitative and qualitative data, in the form of focus groups, surveys and psychological tests.

1.2 Computer Modelling

Simulation has grown hand-in-hand with the computer, though it is only within the last decade that it has been applied to sociology. This has taken the form of *multi-agent systems* (MAS). A social system cannot be defined on a global level, because it is the model's constituent elements (humans in this case) which define trends and patterns in the macroscope. A MAS acknowledges this by allowing the entire system to be composed of many individual parts, all which have their own pre-defined behaviour. It allows the non-linearities between humans to emerge and their individuality to be quantified. These systems can then be used to study the dynamics of the artificial society; in order to support various social theories, and to gain new insight into global behaviours.

1.3 Motivation

The intention of my project is to create a multi-agent system which is capable of modelling the dynamics which occur within the family environment. The family is so fundamental to the creation of a child's character, that taken in the context of chaos theory, it is undeniable that it has a profound impact on the state of any society. Character formation is the first link in a series of chain reactions which will affect both the human in question, and to a varying degree the entire state of society.

Consider the influence of a dictator on the daily habits of his people. He rose to power via a long and complex series of interwoven interactions, which started at birth. Taking into account modern social theories regarding the nature-nurture debate, many would argue that the care he received as a child had a staggering impact on his fundamental nature, belief-system, and hence who he grew to be. In an alternative family environment he may never have considered a career in politics, and thus the entire state of the society could have been effusively different.

There are systems in existence which model social structures like the family unit, business organisations, and politics. However, there are none which explore the unequivocal affect of family dynamics on character formation, and the resultant affect this has on society. I intend to bridge this gap. My focus on the model will be how familial traits pass down through generations, as a result of the childhood environment. My intention is to produce a mathematical standpoint on the nature-nurture debate, and specifically an insight into narcissism.

This latter objective is of particular interest. Narcissism is a psychological disorder that is inexorably linked with the family dynamic, since it can only be formed during childhood. It is characterised by vanity, conceit, egotism and selfishness. The term came from the myth of Narcissus, a handsome greek youth who was punished by the gods for his cruelty and lack of empathy. Sitting by a pool of water, he fell in love with his own reflection…a love that could not be returned. Cursed to feel the pain of unrequited love forever, he eventually killed himself. This is remarkably adept at conveying the meaning of narcissism.

Narcissus was egotistical and selfish, loving his image at the expense of himself. Desperately wishing for his reflection to love him back (i.e. self-love), he was destined to wither and die. This portrays the essential paradox of narcissism. Narcissists believe they are wonderful, intelligent people, leading to behaviour which is self-centred and arrogant. But in reality, they are masking their true nature, to which they are only subconsciously aware: an empty well of self-esteem and an utter lack of love for themselves.

This is highly complex behaviour to model. Nevertheless, by basing my abstraction of narcissism on a firm foundation of psychology, it will be possible to observe its spread through a society, and witness its effect on the family environment. This will tie in with my study of the family's influence through time, because narcissism often portrays cyclic behaviour, whereby interactions with a narcissist parent are more likely to produce narcissism in the child. This provides a generational perspective of the family's influence. The ultimate aims of this project are therefore to validate social hypotheses relating to narcissism, to accurately model the family subsystem, and to witness its effect on the overall state of society.

1.4 Contributions.

The main contributions made by this project are as follows:

- The design of a conceptual model which can be used in the simulation of human societies, with particular emphasis on the family environment.

- The implementation of this model, providing mechanisms for simulating interactions within a variety of locales, and providing a wide variety of tools for the analysis of families and the society.

- The introduction of external affectors to an otherwise contained environment. This takes the form of mass-traumatisation, and family-counseling.

- The modelling of the psychological disorder narcissism, with particular emphasis on its underlying psychology, the affect it has on the global system, and its relation to the family environment.

2. Background

2.1. Simulation:

Computer Models attempt to simulate an abstract notion of an individual system, in order to glean certain outcomes:

- *To understand the behaviour of the existing system* (for example, why do two specific atoms bond at a certain temperature, and why does a network system crash if more than 10 users are working?)

- *To predict the effect of changes to the system* (for example, would parallelisation of computer processors in a system cure the problem of slow-down during garbage collection?)

- *To study new/imaginery systems* (is the creation of a new routing algorithm for un-addressed packets over the internet feasible?)

All three of these outcomes can, and indeed have been, called into play when considering systems of human agents in an artificial society. We have been able to model the rise and fall of dictators (and hence gain new insight into the mechanics of mob-mentality). We can use accurate models to observe/predict the changes that occur when external factors are applied (such as stock-market crashes and poverty). New and imaginery systems can even be created in the form of utopian societies.

The first known model was put into practice under the Manhattan Project (WWII). This modeled nuclear detonation, through the use of twelve 'hard spheres' (impenetrable spheres which cannot overlap in space used to represent particles), alongside a Monte Carlo algorithm. However, simulation has many fields of application, including chemistry, biology and finance.

The lines of distinction begin to blur when we move into the social sciences. Whereas the aforementioned types of model bear relation to strict mathematical formulas, and adhere to steadfast laws and physics; human cognitive simulation is a veritable minefield of uncertainty. There are several ways to approach the problem:

- If we were to look at the problem physically, with knowledge as purely cellular activity, we come across the hurdle of the *mind-body* problem. The interactions of trillions of neurons exceeds our capabilities for relating it directly to human sentience and the complexity of our beliefs and thought processes. To understand this emergent phenomenon of an almost metaphysical endowment of knowledge is not currently possible.
- Another path is to abstract away the body, and concentrate solely on the mind – in terms of our knowledge of psychology. There has been much progress in this field over the last century; though with no physical data, any explanation of human behaviour is destined to remain conjectural.

- Finally, we can base our model purely on observable behaviour. This is the safest route to take, because it enables us to match our model to empirical data. However, this method usually involves averaging of results, which holds the danger of losing agent individuality.

The method of simulation I shall undertake shall follow a combination of the latter two approaches. I believe this will allow me to gain realistic results, from a strong base of understanding; and hence this will allow me more insight into the mechanics of individual agents. This is of vital importance for my system in particular, because I shall be handling rather complex behaviours, and I will also be concentrating on the local (rather than global) spread of information.

2.1.1. Agent Based Simulation:

This is a specific type of modelling, in which the overall behaviour of the system is far too complicated to simulate on a global level. Rather, the system must comprise of many interacting agents, all of which behave of their own accord. For example, in particle dynamics we look at how the movement of individual particles interacting with each-other emulates the overall motion of the system. We can also look at ecology, with the population dynamics of salmon or trout: It was discovered that purely mathematical models which assume that each trout behaves identically neglected their individuality and hence the model's realism.

This is of vital importance in my model where the agents shall be human; since in general, no two humans behave exactly the same.

2.1.2. Conclusion:

My simulation will be a multi-agent, discrete event system, with continuous states, discrete time, and stochastic transitions. Agents shall interact based on rules assembled from psychological theory and empirical data.

2.2 Narcissism

Here, I will give some practical accounts of narcissism, in the form of a case study and an interview with a psychologist. Note that a full account of the characteristics and causes of narcissism will be provided in Chapter 3, under the section 'Narcissism and the Model'.

2.2.1 A Case Study

Here is a description of the causes of narcissism, taken from an actual account of a patient with the disorder [SgWlm]. The kind of treatment described is typical of the upbringing of a narcissist.

> Patti was an active person who enjoyed walking and travel, but had not managed to develop any of her interests into a career. She could not stick to anything long enough to become good at it. She did not say so, but her descriptions of her parents conjured up people who were intolerant of her feelings and needs. They wanted her to grow up as fast as possible and had not enjoyed her being a dependent baby. She had not been breastfed. If she cried out at night, her mother didn't come. Her mother's needs came first. She could not wait to get away from the children, to shop for nice clothes, have an affair, enjoy her holidays. Someone else was always left on the beach with the children. She was not every interested in them or their company. Worse, when Patti inconvenienced her, for example, by knocking over a special vase that her mother had forgotten to put away, her mother would lash out with fury and hit her. She was frequently punished. Patti grew up feeling she was clumsy and stupid, and focused on trying hard to please others by being helpful. She attempted to be a sensible, grown-up person, yet inside she always felt like a little girl in a world full of grown-ups, Alice in Wonderland, lost without the rule book. She would try to have the feelings she thought were expected of her, but she had great difficulty in knowing what she was really feeling. Negative feelings about other people were particularly taboo. This story is typical of the experiences of a 'narcissistic personality disorder' – the kind of experience which might lead to a vulnerability and depression.

2.2.2 Interview with Sandra Yarwood:

I was lucky enough to secure several interviews with a noteworthy psychologist PHd, Sandra Yarwood[SY], who has had many years 'in the field', dealing with a variety of narcissistic patients. She was able to offer valuable insight into the psychology behind narcissism, and also provide many useful references points, and access to empirical data. Below is an extract from one of these interviews:
(SY refers to Dr. Yarwood, and DB refers to myself).

DB: What is narcissism?

SY: Narcissism is a personality disorder which means that the sufferer can only relate to others in so far as they can use or exploit them to meet their own emotional needs. This isn't as easy to spot as it sounds. There is a series of traits (I think about 8 in the US clinical definition) which if at least 5 are identified indicate that someone has Narcissistic Personality Disorder. In common culture ‘narcissistic’ has come to mean selfish or self-obsessed, but narcissists come in different forms and in different degrees of severity. One common trait is lack of empathy, but this is also a trait of other personality disorders such as Borderline Personality Disorder, so is not enough in itself. Another trait is a craving for admiration and recognition, but in some narcissistic configurations this has been superceded by powerful fantasies and being out of touch with reality which makes actual admiration irrelevant as it is always imagined.

DB: What is the biggest affector in creating narcissism?

SY: Everyone starts out as a narcissist as a baby doesn't understand that they are not the centre of the universe, and we also need a certain level of narcissism or we wouldn't have any self-esteem or feel the urge to protect ourselves. Moving on from a narcissistic state is an essential part of human and personality development. As the baby develops it begin to understand that it is separate and dependant on another being, and it begins to learn to relate to that other and from that to others and the outside world. How does this go wrong? One of the important factors in developing NPD is a lack of mirroring and consistent love and affection as a baby, which leads to the lack of a secure base. Children need a sense of a secure base (a consistent carer) in order to venture, learn and explore, and those who don't get it tend to fall back on relying on themselves. They become their own secure base, so instead of building up a pattern of mutual relating which benefits both sides, they don't learn mutuality and only know how to bolster themselves. Their relating then becomes distorted into using others. It is likely that the earlier this failure of their development occurs and the more consistent it is, the more intractable the problem becomes.

DB: What are the common defence-mechanisms of a narcissist?

SY: An individual will develop different strategies to cope with anxiety and threat, so there are different paths along which NPD can develop. Some narcissists need everyone else to see things their way, while others recede into their own world in order to keep their views separate. These are described as adherent and avoidant narcissists. Some narcissists constantly draw attention to themselves quite blatantly craving attention and seeming to ignore even blatant criticism or evidence that they are not superior, while others are painfully sensitive to criticism, interpreting the most inoffensive remark as if it had to be about them. The latter type can be a puzzling combination of arrogant and punitively sensitive to criticism, and they are described as thin-skinned narcissists and the former as thick-skinned.

DB: How does it manifest itself in relationships?

SY: They can't have proper relationships and they can't really love anyone else.

DB: Can it be cured?

SY: It depends on how deep seated it is. A really grandiose narcissist who has no sense of reality and no awareness of others is not going to shift easily. Those who have some self-awareness, but slip into narcissistic relating in their intimate relationships as a defense mechanism to ward against making themselves vulnerable are better candidates for therapy.

2.3 Humans as Artificial-Agents:

2.3.1 Fundamental Concepts:

The underlying bases of any multi-agent system (MAS) are the concepts of agent knowledge, environment, and society (the latter can include the trivial set-covering society). This is true in all cases, whether the agents are humans, birds, or even molecules.

2.3.1.1 *Knowledge*:

Every agent in the MAS must have knowledge of how they react to external events. For example, in physics, the particle agent should know about the effects of a collision with another particle: what loss of energy occurs, in which direction is the rebound and what is the rate of deceleration? When these relatively simple laws are scaled upwards to say a human agent, the laws of interaction and self-deliberation become much more subtle.

2.3.1.2 *Environment*:

This is the primary cause of change in state for any agent. It is the agent's interactions within its local environment that determines its relation to other agents and its own internal reaction.

2.3.1.3 *Society*:

This is regarded as a collection of agents, characterized by having common interests and often having its own distinctive culture. Though it can appear in many types of system, it's most pervasive with humans. Since the human mind exhibits differing behaviour dependent on situation, from logical thought processes to random or irrational actions, it is natural that new societies are born, where the similar flock together. This can be seen throughout time, from primitive pre-modern cults and tribes, to the more developed political parties and religions across the world. On a more micro-scale, we can include families as a type of society. Albeit small, they have their own set of (usually congruent) beliefs, and their roles within this society determine the psychosocial interactions that take place between members, and also among outside agents.

2.3.2 Cellular Automata:

The basic idea of building a multi-agent complex system (see section 2.6) is not to try and describe the system from “above” – i.e. illustrating the complex system with a set of complex equations, but rather by letting the complexity emerge from the interaction of simple individuals following simple rules.

Accepting agent-knowledge and environment as a way of modelling behaviours, we arrive at the most prominent medium for displaying such agent dynamics: *cellular automata*. In the 1940’s, it was the Polish mathematician Stanislaw Ulam who co-founded this concept alongside John von Neumann, whilst studying the growth of crystals and self-replicating robots respectively.

2.3.2.1 The Cell:

This is the basic building block of the cellular automaton (CA). It is a memory element which stores a state – and in the simplest cases (as in Ulam’s discovery) it would take one of the binary states, 0 or 1. In more complex simulations, the number of states could be (uncountably) infinite; though in practice, the storage of state is usually in the form of floating point or double numbers, which inevitably leads to rounding and hence a cut-off point. A cell’s state could even comprise of a number of separate attributes, each of which has its own state: and indeed, this shall be true of my simulation.

2.3.2.2 The Lattice:

These cells were arranged in a spatial web, or 2D lattice. The states of each cell could then be visualised by assigning a colour to each possible state (e.g. for binary states, black for 1 and white for 0).

2.3.2.3 The Neighbourhood:

Up to this point, the arrangement of cells has led to a static system. To introduce *dynamic* into the system, we must define a set of rules, which determines the state of each cell at the next time step. These rules typically apply to the neighbourhood of each cell, determining the cells next state by:

1. The cell’s current state and
2. The configuration of its neighbours.

There are several types of neighbourhood which can be used for a typical 2D lattice.

- **Von Neumann Neighbourhood**:
  This definition takes a *radius* of 1 around the cell as its neighbourhood. The cell above, below, to the right and to the left.

- **Moore Neighbourhood**:

  This is an enlargement of the von Neumann neighbourhood, since it also contains the diagonal cells. (radius = 1). This can be described in mathematical terms, by defining the cell-space as:

  $$L = \{(i,j) \mid i, j \in \mathbb{N}, 0 \le i < n, 0 \le j < m\}$$

  (where *n*, *m* are respectively the width and height of the lattice, and *i*, *j* are the row and column numbers of the cell in question). The Moore Neighbourhood is therefore:

  $$N_{i,j} = \{(k,l) \in L \mid |k - i| \le 1 \text{ and } |l - j| \le 1\}$$

- **Extended Moore Neighbourhood**:

  Similar to the basic Moore Neighbourhood, this paradigm extends its reaches to further adjacent cells (i.e. a higher radius is used). See Figure 1.3 for pictorial descriptions of these three neighbourhoods.

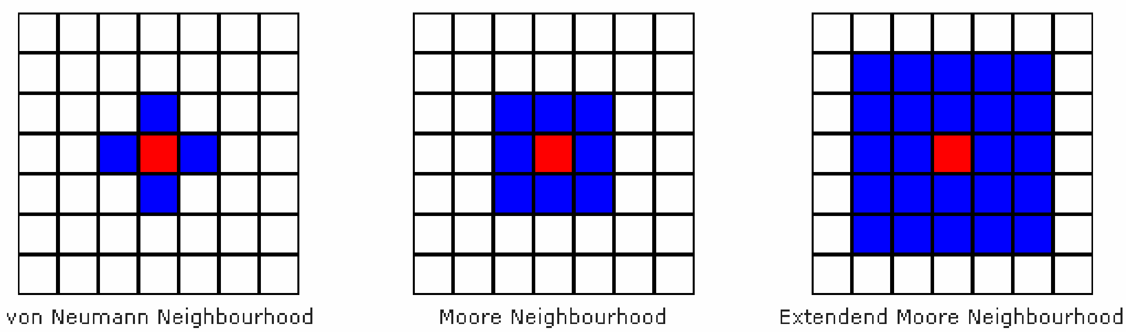


Figure 1.3. *Cellular automata showing different types of neighbourhood. The red cell represents the cell in question and the blue cells represent its neighbourhood.*

For practical purposes, the number of cells in the lattice has to be finite, so the obvious question arises: "*when considering the above neighbourhoods, what should be done with border cells?*" In a 10 by 10 lattice, about 40% of the cells are border cells, in a 100 by 100 lattice, about 4% of the cells are of this kind; so the description of these neighbourhoods need to be altered. A popular solution is to "stick together" opposite borders of the lattice, to create a *torus.* In my model, I shall be using a toroidal lattice, and will apply rules via the Moore Neighbourhood. I experimented with extending the Moore Neighbourhood, but I found that interesting results became too easily dispersed. In addition, my simulation will be concentrating essentially on very local areas of interaction.

2.3.2.4 Applying Rules:

A simple analogy for describing the macroscopic behaviour resultant from local interaction would be the "Mexican Wave" in, say, a football stadium. The neighbourhood would be defined as the person sitting to either your left *or* your right. When your neighbour stands up, you stand up too, and when your neighbour sits down, you too sit down. **Local interaction leads to global dynamic.** There are three types of rule (though I shall omit the third class of 'Legal Rules' since they bear no relation to my project).

1. *Configuration Rules*: An agent can change its state depending on the configuration of neighbourhood states. This can include its own state, and/or a selection of neighbour states. There will need to be a rule for every configuration of neighbours in the neighbourhood/selection (though blanket rules can be used).

   If we consider only whole-neighbourhood configurations, we can say that in general, the number of rule sets available can be calculated with $k^{k^{n}}$, where k is the number of cell states, and n is the number of neighbours (including itself). For a 2D lattice, using a Moore neighbourhood of radius 1, we can see that this gives: $2^{512} = (1.34*10^{154})$ rule sets. Thus, even for this simple CA, we can extract a plethora of possible behaviours. This double-exponential growth underlines the number of pathways towards the system's outcome, and therefore the need to select rules wisely.

2. *Totalistic Rules*: Agent state changes depending on the sum of the states in its neighbourhood. This class of rules is used in The Game of Life (see section 2.3.4).

   An example of a possible totalistic rule for a binary 1D lattice with radius=1, can be seen below, (where $z_i(t)$ represents the state of cell *i* at time *t*):

$$z_i(t+1) = \begin{cases} 1, & \text{if } \left(z_{i-1}(t) + z_i(t) + z_{i+1}(t)\right) = \zeta \\ \ldots & \\ 0, & \text{otherwise} \end{cases}$$

This grid would evolve over a number of discrete time steps, with each cell determining its state for the next iteration based on the states of neighbouring cells, and a set of rules.

2.3.3 Classes of Automata and the Edge of Chaos:

"...many (perhaps all) cellular automata fall into four basic behaviour classes."
Stephen Wolfram (Wolfram, 1984).

Wolfram was a pioneer in the field of cellular automata, and amongst other successes, he devised separate classes of automata based on geometric analogies. These segregate their properties based on complexity; a subject which shall be discussed further in Section 2.5.

Class I: Limit points (all starting configurations lead to the same uniquely fixed state).
Class II: Limit cycles (oscillating patterns).
Class III: Chaotic Behaviour
Class IV: More complex structures, capable of *universal computation.*

Wolfram commented that a good example of Class IV is the popular Game of Life. This class bears the property of *universality*, meaning that it is capable of performing any finite algorithm. The initial configuration of the state-space can be likened to the program and input, with the solution evolving through iterations. However, this property is exhibited only where the initial conditions greatly affect the dynamics of the automata. This is the foundation of *chaos theory*.

It was Christopher Langton who observed that the most 'creative' behaviour in a dynamical system occurs at "*the edge of chaos,*" i.e. where a single parameter can ignite the transition from order to chaos. A good example of such behaviour is a room full of people. This is an unstable situation, because there are a multitude of possible actions that could occur, which could result in both extremes of order. If everyone stayed still, we would have a static situation. If any person pulled out a gun, the other inhabitants would panic – i.e. chaos. People will get up and leave the room, others will enter, and a throng of different activities could be undertaken. A conversation could begin which is ignored (which has an associated transient of 0), it could be interesting enough to start a chain, whereby it is passed from friend to friend before dying out (a short transient). In some cases, the content could be so compelling that the chain reaction grows in strength and is spread ad infinitum (theoretically an infinite transient), until it changes the entire world. For example, 120 years since Karl Marx released his 'Communist Manifesto', his words are still taking effect.

A system such as this, which is midway between stable and chaotic domains, is also referred to as being in *self-organised criticality* and is the where the interesting behaviour that Langton refers to occurs.

He thus sought to parameterise regions of CA based on their dynamical properties, i.e. their state of order-chaos. This parameter measured the probability of a cell being alive in the next generation (taking values between 0 and 0.5 - exceeding this maximum leads to an inverted system). In a CA with 'Q' states, and neighbourhoods of size N, we can calculate this parameter (λ):

> Let ($s_q \varepsilon Q$) be the quiescent state (i.e. core state), with n transitions into s_q.
> The remaining (Q^N-n) transitions can be filled randomly from the set of states $Q/\{s_q\}$. Therefore, we can say:

$$\lambda = \frac{Q^N - n}{Q^N}.$$

With the probability of cell genesis/survival calculated as such, the CA's had the following characteristics:

λ	Behaviour
0	All cells die in following step
0 < λ < 0.3	Class 2 behaviour – periodic patterns, taking longer to stabilize for higher **λ.**
~0.3	**Critical Point –** Class IV automata
~0.5	Class III automata

It is at this critical point which we find the edge of chaos. Below it there is too much order for any interesting behaviour to occur, and above we find too much chaos for any complex structures to remain stable. Only around this critical point can "*real life*" occur.

I had done my own experiments relating to this argument, before I had even come across this theory. In my early system, I tested the effects of allowing the agents to roam around the state-space, interacting randomly with other agents. I found that with a small number of agents, interactions were too few for any emergent behaviour to arise. With too many agents, overcrowding occurred, and any behaviour averaged out over the entire state-space. I found that there was a critical point – in which suddenly interesting dynamics and segregation began to occur. Each of my experiments confirmed the existence of a critical point, and this has thus been considered during the remainder of my development.

2.3.4 The Game of Life:

This is the best known 2D cellular automaton, and was invented by John Conway[URLa] in 1970. Originally it was 'played' on a board with counters being moved by hand, but implementation on a computer greatly increased the ease of exploring patterns. It has been explored considerably, and a number of extraordinary patterns have been produced. As described in Section 2.3.2, we have a situation where each cell can take an 'on' or 'off' state (or more appropriately for this example: 'dead' or 'alive'). The game is interacted with by setting up an initial configuration of cells and observing how it evolves, according to the game's simple rules (see below). These were created in such a way that patterns could disappear, remain stable or grow infinitely, without the 'seed' pattern immediately giving away which.

1. A living cell with less than two living neighbours dies (as if by loneliness).
2. A live cell that has more than three live neighbours dies, (from overcrowding).
3. A dead cell with exactly three live neighbours will come to life.

An example of one such iteration is shown in Figure 1.2. The numbers on each cell represents the number of living neighbours it has, and hence whether it will live/die, depending on the given rules. The pattern given here stabilizes, but if a seed of three live cells in a row is used (rather than four), the pattern oscillates infinitely around its centre point. From seemingly simple starting states, we have already been able to garner some interesting results from the evolution of this society.

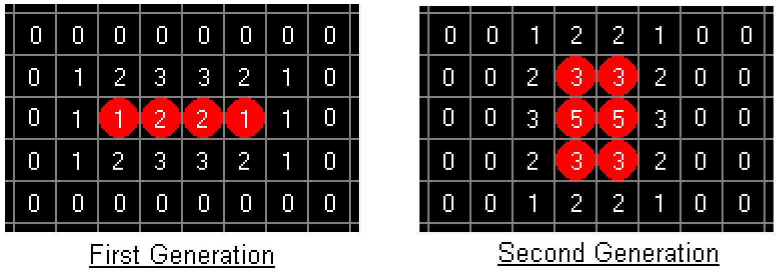


Figure 1.2: Game of Life Board changing after one iteration.

I created my own version of The Game of Life, to become acquainted with the workings of cellular automata in general (see Figure 1.4). I discovered that by changing the rules, I could create wildly different behaviour in the game. This will be important when considering the impact of changes in my model to its emergent features.

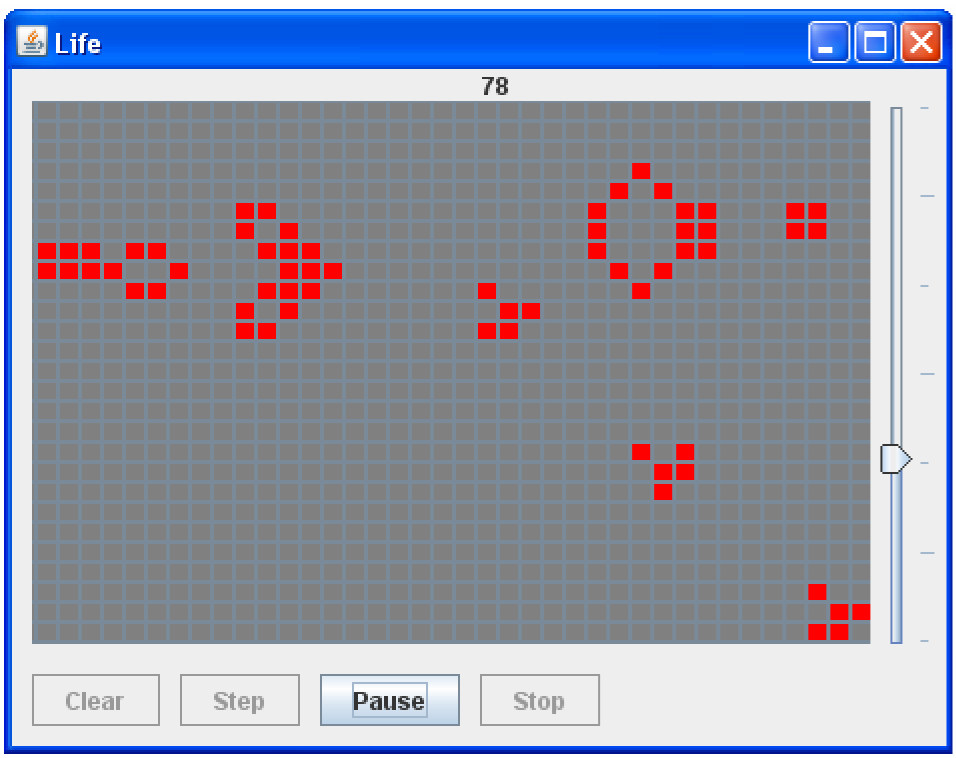


Figure 1.4. *My own version of The Game of Life, displaying the famous Gosper Glider Gun – an infinitely cycling pattern.*

2.3.5 Conclusion:

Complex patterns have emerged from very simple rules in the case study given above; noted for being visually appealing, and for some interesting behaviours, including self-replication. It is precisely this behaviour that has led to such interest in using cellular automata in order to model a particular system, by providing more significant local rules of interaction.

"At each level (of the prebiotic, biotic and social evolution) new properties appear that cannot be explained by the sum of the own properties of each part that constitute the whole. There is a qualitative gap (…) the property of emergence is linked to complexity."
(J. Rosnay, 'Le macroscope - Vers une vision globale').

It should be noted that for a grid which uses only two states, each neighbourhood (i.e. an agent and its immediate surrounding neighbours) can produce $2^9 = 1024$ different patterns. Even the minimum number of cell states can produce complex and diverse behaviour – which, along with its innate propensity for emergence, makes it perfect for modelling the complexities of human dynamics.

2.4. Self-Reproduction.

All of the examples of agent-based systems given so far have been of passive societies; whereby agents make decisions depending solely on their environments. However, as I have already mentioned, environment is only one potential ingredient of a model. In the 1980's, Christopher Langton decided to introduce agent *knowledge* into the system, in the form of self-reproduction.

Adding such knowledge increases the complexity of the model, leading to much more interesting emergent features. In particular, self-reproduction is an imperative aspect of modelling human systems. Not only is it necessary to maintain the agent-pool through reproduction, but it can also be used to model *learning.*

Langton's project was an extension of Von-Neumann's *Universal Constructor* – a complex theory of self-replicating machines, which drew inspiration from cellular reproduction in nature. Whereas this claimed the potential to create any other automaton given its description, Langton created a structure which was exclusively capable of self-reproduction; a task which was several orders of magnitude less complex than von-Neumann's failed venture.

2.4.1 Langton Loops:

Langton's Loop[URLb] is a cellular automaton, named so because it dynamically stores data inside a square sheath (coloured red in Figure 1.5). The data is stored as a sequence of instructions for reproduction which direct the constructing arm. This data turns counterclockwise within the sheath, creating a new loop (with the appropriate reproduction code). The new loop can now reproduce itself, and the process continues recursively for as long as required.

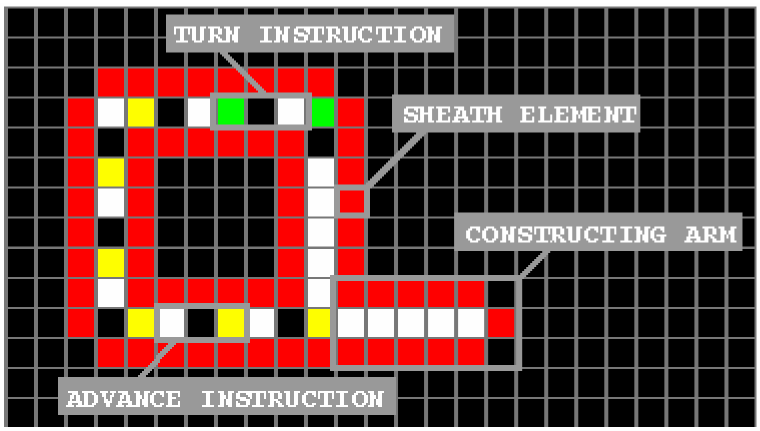


Figure 1.5: *The initial setup for iteration 0 of the Langton Loop.*

The two data instructions within the Langton's loop are very simple. The first (which is identified by the yellow element in the figure) tells the arm to advance by one position, while the second (green in the figure) directs the arm to turn 90^o anti-clockwise.

After three such turns, the arm will have looped back on itself, at which stage a 'messenger' starts the process of severing the connection between the parent and the offspring, thus concluding the replication process. At this stage, the parent loop can proceed to construct another copy of itself in a different direction, while the offspring itself starts to reproduce. The sequential nature of this self-reproduction process generates a spiralling pattern through space (see Figure 1.6).

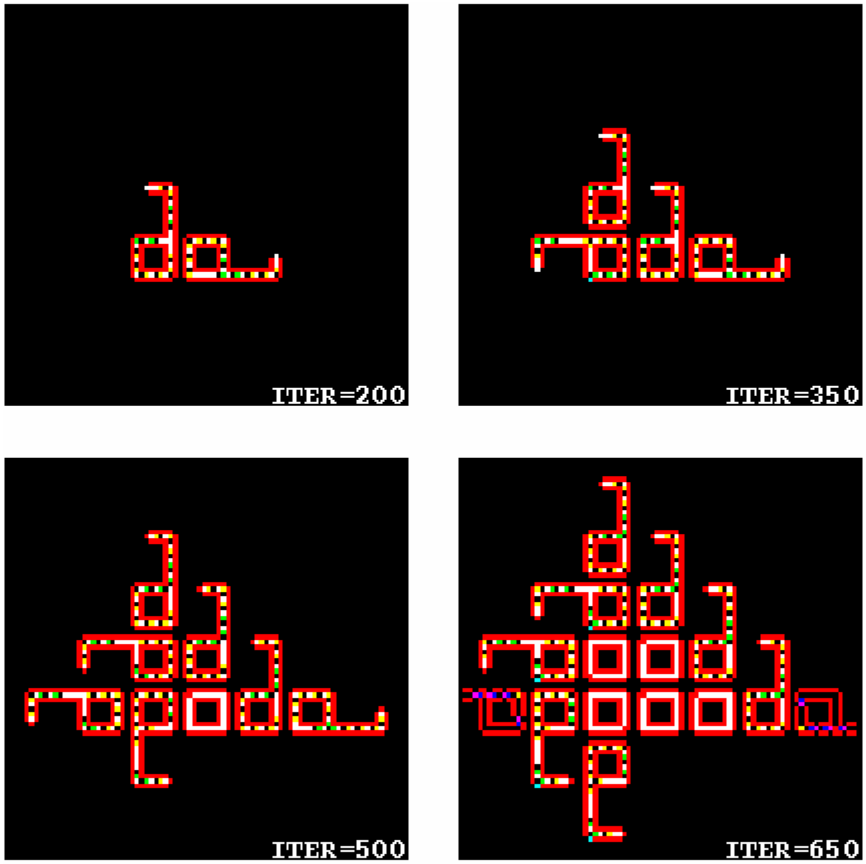


Figure 1.6. *Langton Loops self-reproducing*

These loops ignore the argument for individuality, as discussed earlier, hence the ordered nature of the emergent fractal-like patterns. However, the data which the loops contain could be considered to be 'Agent-Knowledge', and though simple, it is the basis for bridging the gap between passive societies, and active ones. With purpose behind each agent and a dynamic environment in which to operate, we have the beginnings of *life*. By giving the agents knowledge relevant to the human condition, we have the beginnings of human civilisation.

2.4.2 Genetic Algorithms.

Genetic Algorithms (GA) are adaptive heuristic search functions, used for finding optimal solutions in a given *phase-space*. Their basic concept is to simulate the processes in natural systems necessary for evolution, specifically those relating to Darwinian theory. By operating on a population of potential solutions and applying the principle of 'survival of the fittest', at each generation a new set of approximations is created by selecting individuals (phenotypes) via a fitness function, and breeding them together using variation-inducing operators borrowed from natural genetics (such as crossover and mutation). This process leads to populations of individuals that are better suited to their environment than their predecessors, just as in natural adaptation.

This robust technique has been applied in many fields of engineering with great success – proving to be adaptive to changes in input, and acting efficiently even where the phase-space is large or misunderstood.

1. **[Initial Population]** Generate a random population of chromosomes which represent suitable solutions to the problem. Evaluate the fitness of each chromosome *x* using a fitness function *f(x).*
2. **[Selection]** Select two parent chromosomes from the population, with higher fitness levels yielding a higher probability of being selected.
3. **[Crossover]** Cross over the parents to form new offspring (with no crossover performed, children are genetic replicas of the parent).
4. **[Mutation]** With a mutation probability, mutate new offspring at pre-set/random positions of the chromosome.
5. **[Test]** Return best solution if the objective function has been satisfied, else loop back to step 2.

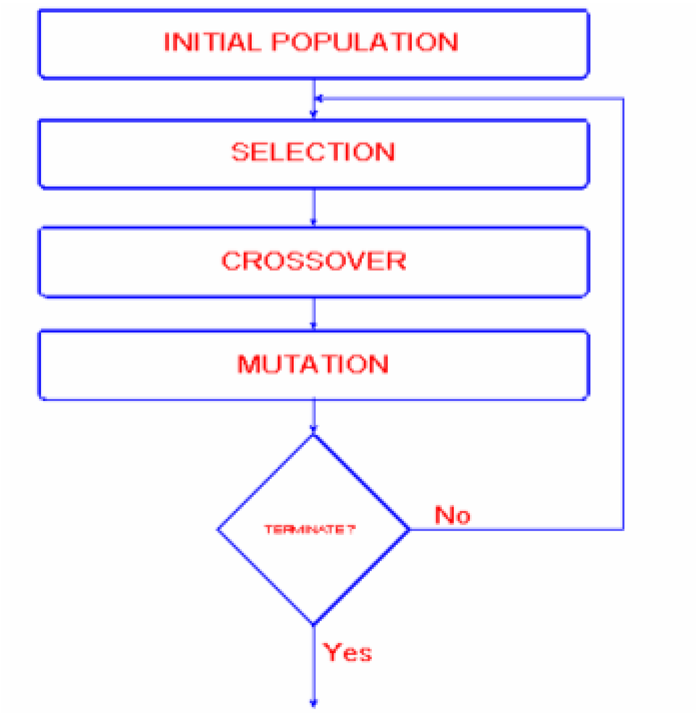


Figure 1.7. *Flow chart of the stages of a genetic algorithm.*

I shall briefly explain the three prominent features of the genetic algorithm with the use of an example, which follows the most evident choice of natural evolution. In this case, we step back 45 million years to examine the Basilosaurus. This creature was a prototype of the whale genus, with posterior paws and a quasi-independent head. The short length of its front paws required the Basilosaurus to move with a series of undulating movements, which took up far more energy than required by the whales of today. As a hunter, this deficiency was a hindrance, so over time, natural selection rectified this problem. In my example, I'll be looking at two specific features of the Basilosaurus which need to be changed to be better adapted to an aqueous environment: the shortening of the anterior (front) paws, with the locking of the elbow to aid articulation of movement; and lengthening of the 'finger'-bones to constitute the base structure of a flipper.

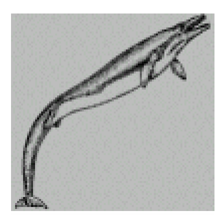
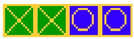


Figure 1.8.
The Basilosaurus

In this simplified example, we'll say each creature is represented by a chromosome consisting of four genes. The first two genes represent the length of the paws, and the second two represent the length of the fingers. In our representation of the genome, the circle on a blue background depicts the activation of its respective feature, and the cross on a green background depicts its deactivation. Therefore, the ideal genome (of short paws and long fingers) is  :

If we take an initial population of four Basilosaurus (see stage 1 of algorithm above), one possible initial population could be as shown in Figure 1.9.

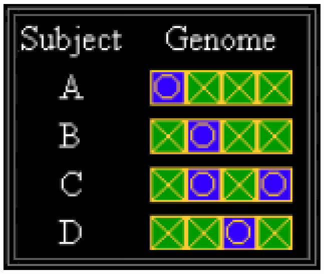


Figure 1.9.
Initial Population of the Basilosaurus

2.4.2.1 Selection:

We can see from Figure 1.9 that subjects A and B are closest to their Basilosaurus ancestors with long paws and short fingers, whereas D is closest to the optimum (it just requires a small lengthening of the fingers). We therefore have to give each subject a fitness level based on these properties. This can be done quite simply in this example, by giving subjects a point for each gene that corresponds to the ideal (see Figure 1.9). However, this can lead to problems, such as a super-subject converging the entire population to their genome. The population would no longer be diverse enough to allow continuing evolution with the genetic algorithm. There are cures to palliate artifacts such as this however, such as using exponentials:

$$\text{Fitness} = \sqrt{(\sum(\text{gene corresponding to ideal}))} + 1.$$

This reduces the influence of the strongest candidate.

Subject	Fitness	Reproduction probability
A	1	1/7 = 0.143
B	1	1/7 = 0.143
C	2	2/7 = 0.286
D	3	3/7 = 0.428
Total	7	7/7=1

Figure 1.10. *Fitness Function*

2.4.2.2 Crossover:

At this point, we'll consider a reproduction cycle which procreates four new members to the population. With the fitness levels calculated above, a possible effect of this cycle would be D getting selected four times (and hence having four new descendents), with C getting selected twice as D's mate and A and B each getting selected once. With two parents selected, the process of crossing-over their genes needs to occur. There are several ways to do this.

With a single-point crossover, one crossover point is selected, from which the offspring is created as a splice of each parents genes. This is shown pictorially in Figure 1.10 (a). To aid clarity, I have extended the length of each gene and shown them as a binary variable (with 1 indicating activated, and 0 as deactivated). Two-point crossover (as in Figure 1.10 (b)), is where two random crossover points are selected. The offspring is generated from the beginning of Parent A's chromosome to the first crossover point, then Parent B's binary chromosome between the two crossover points, and finally Parent A's chromosome, from the second crossover to the end of its chromosome. The third variety is the most oft used, with bits being assigned randomly from each of the parents. (To follow nature more closely, one could even extract the notion of dominance in genes, with a binary arithmetic conversion such as XOR).

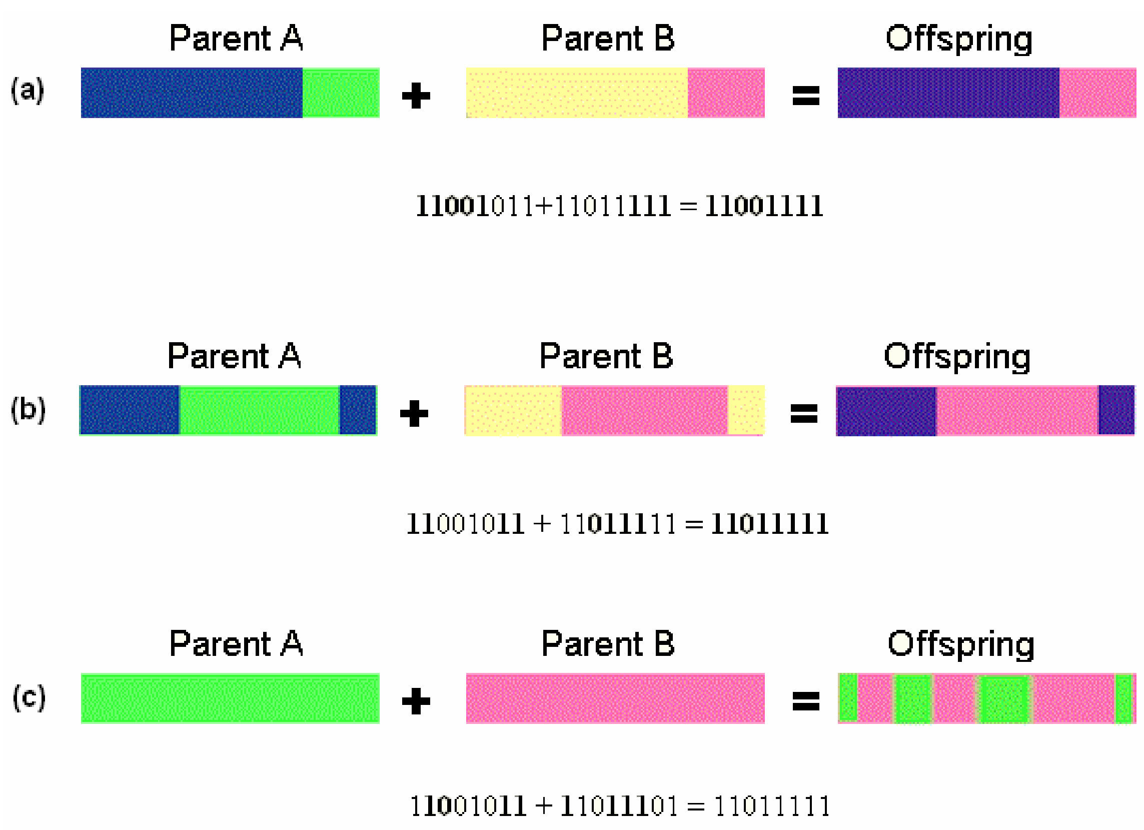


Figure 1.10 *Different crossover methods for a genetic algorithm. (a) Single-point crossover, (b) Multi-point crossover, (c) Uniform crossover*

With my example, I am using genes of very short length, so I will be taking a single crossover point. The pattern of reproduction for Subject D is shown in Figure 1.11). Here, the crossover point has been randomly selected. During the next cycle of reproduction, C' and D' are most likely to procreate, and will have the common descendent E.

D' : X X O + C' : O = X X O O

This is the ideal subject we had been looking for: its paws have become flippers. It now has the highest possible fitness value, and hence its genes will flood the rest of the population. If the two Basilosaurus features mentioned are the only measure of fitness, then this new breed of whale will remain the best, until a new external event alters the whale's ability to survive. Hence its fitness value will drop, and a new breed of whales will need to emerge from the current population, in order to avoid extinction.

Subject	Received genes	Genome	Fitness	Reproduction probability
A'	A : O X D : O X	O X O X	2	2/10=0.2
B'	B : X O D : O X	X O O X	2	2/10=0.2
C'	D : X X C : X O	X X X O	3	3/10=0.3
D'	C : X D : X O X	X X O X	3	3/10=0.3
Total			10	10/10=1

Figure 1.11. *Reproduction Cycle for Subject D.*

2.4.2.3 Mutation:

This additional operator serves to explore the phase-space of the algorithm. In natural terms, it allows completely new features to arise from a population which aids their survival (e.g. imagine a blind land-dwelling creature forming light-sensitive cells on its head. This would give it warning of when a bird of prey was swooping above). Computationally, it maintains the diversity within the population by prohibiting premature convergence. For optimisation algorithms, it also solves the common problem of agents becoming stuck at local optima (e.g. imagine robots scattered around a mountainous landscape, which follow steepest paths. When each robot reaches a peak, they claim to have found the optimum).

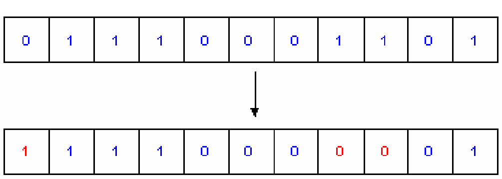


Figure 1.12. *Mutation (red cells indicate mutated genes).*

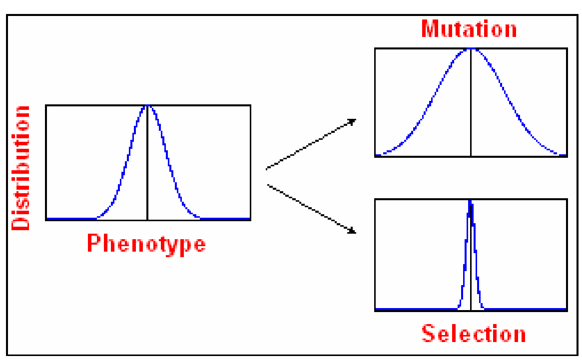


Figure 1.13.
Effect of Mutation and Selection on the range of chromosomes for the phenotype (i.e. active agent).

Implementing mutation is fairly trivial, since all that is required is to alter several random genes of the chromosome. In Figure 1.12, this has been accomplished by flipping several of the bits: Figure 1.13 shows the effect of mutation compared to that of selection.

2.4.2.4 Example Applications:

I shall very briefly explain a couple of example uses of the genetic algorithm.

1) Imagine the *Knapsack Problem*, where objects are given value and size. It is necessary to maximize the value of the knapsack's contents, whilst not exceeding its size. This can be done using binary encoded chromosomes, where each bit indicates whether the corresponding article is contained in the bag.

   Chromosome A: 100110100001100010100100001
   Chromosome B: 110000010011000000010000110

   With an initial population of chromosomes such as those shown above, we can easily retrieve a fitness for each, by summing the value of those articles with a '1' bit. Crossover and mutation will lead to the optimal solution.

2) The *Travelling Salesman Problem*, is where a set of cities and the distances between each is given, and one must find the set-covering sequence of cities which minimises travelling distance.

   The chromosomes can be found with permutation encoding, where each gene represents a number in a sequence. Incorrect offspring are discarded.

   Chromosome A: 1 5 3 2 6 4 7 9 8
   Chromosome B: 8 5 6 7 2 3 1 4 9

2.4.2.5 Conclusion:

While it is true that purely analytical methods of goal-finding are most efficient; they suffer from the intractable weakness that they often do not obey reality, and are adversely affected by 'noise' in the phase-space. On the other hand, we have the computational analogy for an adaptive system. The genetic algorithm both exploits and explores the phase-space simultaneously, by combining direction and chance in an efficient and effective manner. This has earnt it a reputation as a fast, robust and general-application problem solver. I shall be using it in my model, in two situations. Firstly, and most obviously, for realistic reproduction of agents. Secondly, and rather uniquely, as a method of learning. One might primarily consider a neural net as an effective method to achieve these ends, though with the number of agents interacting in my system, the slow-down would be tremendous.

One could almost consider the genetic algorithm to be a primitive form of complex system. Working in unison with the grander and encompassing agent-based complex system, we can expect to encounter some interesting behaviours.

2.5 Dynamical Systems:

The mathematical underpinnings of this project are deeply rooted in the properties of dynamical systems, and therefore I feel it pertinent to give a brief overview of this domain of study.

2.5.1 What is a Dynamical System?

The most enduring feature of our world, and any situation that we might encounter is change. Therefore, any attempt to understand the artifacts of the phenomena we meet in everyday life requires knowledge of how change occurs over time. Through understanding, we can attempt to predict the future of a dynamically changing system, and in some cases, alter the flow of this change.

Thus, a dynamical system in its most basic form is a system which undergoes time-dependent transformations, or *evolution*. This type of system is seen in nature all around us, from the functioning of our neurones to the dripping of a tap; and it therefore has a wide variety of practical applications. These include financial and economic forecasting, environmental modelling, medical diagnosis, industrial equipment diagnosis, and a host of other applications.

Based solely on an initial starting-state configuration and one or more evolution-functions, we can model a dynamical system by repeatedly mapping the state of the system at the current time, to another state at some later time. This process of iterating over an evolution function is the fundamental component of modelling dynamical systems.

2.5.2 Iteration:

Iterations are the simplest means of describing a dynamical system. By repeatedly applying a function to the current state, and feeding the result back into the function, we acquire movement in the state space. Explicitly, given a discrete-time system, we would like to measure the current state at a sequence of specific times; and this is possible when a rule is present to determine the state at time n+1, given the state a time n. If x_n represents the state at time n, this rule may take the form:

$$x_{n+1} = f(x_n)$$

where f(x) is a fixed function over time. We can then obtain the evolution of the system by iterating this function. Therefore, at any time *n*, we can calculate the current state as:

$$x_n = \underbrace{f(f(\cdots f(}_{n\text{times}}x_0)\cdots)$$

A simple example of such iteration is shown in economics, with *compound interest.*

The situation is as follows. Say that John wished to invest money at a bank. Rather than taking the fixed interest-rate option (where interest is a function of the initial account balance, hence procuring linear monetary growth), he opts for compound interest. This updates interest based on the account's current balance.

John deposits £1000 into his account, which offers an annually compounded interest rate of 8%. At the end of the first year, the bank calculates 8% of John's current balance to be £80, and adds this to his account. His balance is now £1080. At the end of the second year, the bank repeats the process by again calculating 8% of his current balance of £1080. This is £86.40, and when added to his account produces a balance of £1166.40.

This iterative procedure can be expressed more succinctly, by noticing its associated evolutionary function. Compound interest is calculated by:

$$\mathbf{f(x_{n+1}) = x_n(1+r)}$$

where x_n is the account balance at year *n*, and r is the interest rate. At *year 0,* we can set the initial balance to be John's first deposit of £1000. Therefore x_0 = **£**1000 and r = 0.08.

Therefore, after the first year, the bank account would hold:

$$x_1 = x_0*(1+r) = 1000*(1+0.08) = £1080,$$

At the end of the second year, this would again be updated:

$$x_2 = x_1*(1+r) = 1080*(1+0.08) = \mathbf{£1166.40.}$$

And so on…

$$x_3 = 1166.40*(1+0.08) = £1259.71$$
$$x_4 = 1259.71*(1+0.08) = £1360.49$$
$$x_5 = 1360.49*(1+0.08) = £1469.33$$

As you can see, the output amount at the end of each year is being input back into the function for recalculation the following year. For a 5-year saving plan, we could write:

$x^5 = f(f(f(f(f(x0)))))$, or $x_5 = f^5(x_0)$. In general terms, $x_n = f^{\,n}(x_0)$.

This re-application of an evolutionary rule to the current state is what is meant by iteration, and is the basic building block of any dynamical system. A graphical application of an iterating system is known as a Fractal, and it offers a more intuitive view of the relationship between human and dynamic systems.

2.5.3 Fractals & Predicting System Evolution:

Fractals are typically self-replicating patterns, which can produce arbitrary levels of detail at any scale. The idea was founded on principles found in nature, such as seen in ferns and the construction of patterns on shells. A classic example of a man-made fractal is Sierpinski's Gasket.

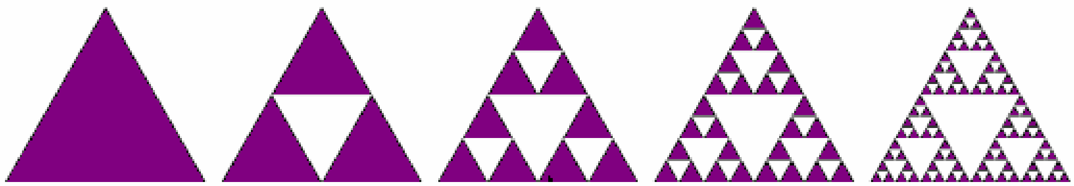


Figure 1.14. *First four iterations in the Sierpinski Triangle fractal.*

This is an example of a dynamic system whose evolution is completely predictable. It is created by removing an inverted triangle, half the size of the original, from the centre of the previous construction. This is then iterated over the remaining triangles. This predictable behaviour is evident in other systems too, including human dynamics. For example, the nature of self-replication is a form of memory-function, and it could also be considered as a role-inhibiting evolution. In a family system, children are likely to mimic the behaviours of their parents, who in turn mimic their own parents: or else they conform to social norms, which come from a nationwide, and then global scale.

However, dynamical systems can be divided into two broad categories: those with predictable behaviour, and those with unpredictable behaviour. The former consist of systems such as the motion of a pendulum, and the rising of the tide; whereas the latter pertains to more complex systems such as the weather forecast and the stock market, which rely on a multitude of different factors.

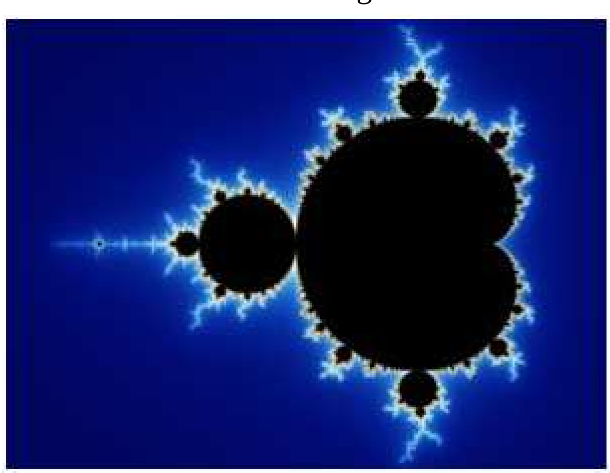


Figure 1.15. *The Mandelbrot Set*

The reason behind this unpredictability has been termed chaos, and just as in nature, appears often in mathematical functions. The idea that simple nonlinear deterministic systems can behave in an apparently unpredictable and chaotic manner was first noticed by the French mathematician Henri Poincaré (see section 2.6).

This idea was expounded upon with the *Mandelbrot Set,* a famous example of a simple function relaying both stable and chaotic behaviours.

This is created from the quadratic recurrence relation:

$$f_c(z) = z^2 + c.$$

Consider the behaviour of the sequence [0, $f_c(0)$, $f_c(f_c(0))$, $f_c(f_c(f_c(0)))$…], where z is initially set to 0.

Consider the case where $c = 1$:

$z_1 = 0^2 + 1 = 1;$
$z_2 = 1^2 + 1 = 2;$
$z_3 = 2^2 + 1 = 5;$
$z_4 = 5^2 + 1 = 26;$
$z_5 = 26^2 + 1 = 677;$
$z_6 = 677^2 + 1 = 458{,}330.$

It is easy to see that this $z \rightarrow \infty$. On the other hand, with $c = 0.15$:

$z_1 = 0^2 + 0.15 = 0.15;$
$z_2 = 0.15^2 + 0.15 = 0.1725;$
$z_3 = 0.1725^2 + 0.15 = 0.1798;$
$z_4 = 0.1798^2 + 0.15 = 0.1823;$
$z_5 = 0.1823^2 + 0.15 = 0.1832;$
$z_6 = 0.1832^2 + 0.15 = 0.1835.$

This sequence quickly converges to ≈ 0.183772234.

Depending on the value of c (assigned to any real number), the sequence may either:

(a) Converge to a fixed point.
(b) Tend to infinity
(c) Oscillate among a number of states
(d) Exhibit no discernible pattern.

The Mandlebrot Set is the set of all values of *c* which do not create sequences that tend to infinity. This area is shown in black in Figure 1.15. Situation (b) occurs outside of this area, and (c) and (d) occur at the border regions: this is where chaotic behaviour is observed. It is here that we reach a saddle point, where new and unpredictable behaviours can occur. This is roughly synonymous to a state of equilibrium in society, where a small push in either direction can lead to a drastically different global state in the future. (Consider the choice to go to war in Iraq. Blair's decision to support Bush may have tipped the scales towards the volatile events of today…a very different world from what could have been).

It is interesting to notice the markedly different behaviour that is exhibited in different regions of the Mandelbrot Set, due to the high *sensitivity to initial conditions* (see section 2.5.5).

"*A dynamical system that exhibits sensitive dependence on initial conditions will produce markedly different solutions for two specifications of initial states that are initially very close together*." - Kellert (1993)

"*Uncertainty is the most certain thing about planetary orbits; the solar system doesn't really run like a clock. Sensitive dependence on initial conditions rules, and chaos lurks everywhere.*" - Peterson(1993).

This sensitivity is typical of systems that have chaotic orbits, and is a common feature of complex systems. We are led towards unpredictable results, and the birthplace of emergence: *order from chaos* (see section 2.6.3.4). Before studying complex systems in detail, it is necessary to understand why such varied behaviour as exhibited above occurs. We therefore look at the trajectory of these sequences.

2.5.4 Orbit Analysis:

By iteratively applying a function infinitely, we gather the collection of points which the function produces, also known as its trajectory or orbit. For both the compound interest example, and the Mandelbrot Set (with c=1), we know that as n → infinity, x_n → infinity, and therefore its orbit is infinite.

The divergence to infinity is a trivial one however, and there are much more interesting orbits with which to concern ourselves. Of particular consequence to my system is the fixed orbit.

2.5.4.1 Fixed Point Orbits:

This type of orbit occurs where f(x) = x. Therefore, every element of the orbit takes the same value. If the seed of a function is the initial value which is taken as input; we find that seeding the compound interest example with 0 produces a fixed point orbit. i.e. f(0) = 1.08*0 = 0. f2(0) = 1.08*0 = 0…and so on. We can find fixed points for many other functions with the following method.

Example: $f(x) = 2x^2 + 6x + 3$

A fixed point orbit is found where f(x) = x, therefore:

$2x^2 + 6x + 3 = x;$
$2x^2 + 5x + 3 = 0;$
$x = -1 \pm ¼$

Seeding the function f(x) with -5/4 or -3/4 produces fixed point orbits. This can be shown graphically.

2.5.4.2 Graphical Analysis:

Employing the use of the graph y = x, we can visually obtain references to fixed points in any system f(x). By the definition of a fixed point given above, any intersection between these two graphs marks the position of a fixed point (since f(x)=x). Hence, for the previous example, the two fixed points are shown circled in red (see Figure 1.16).

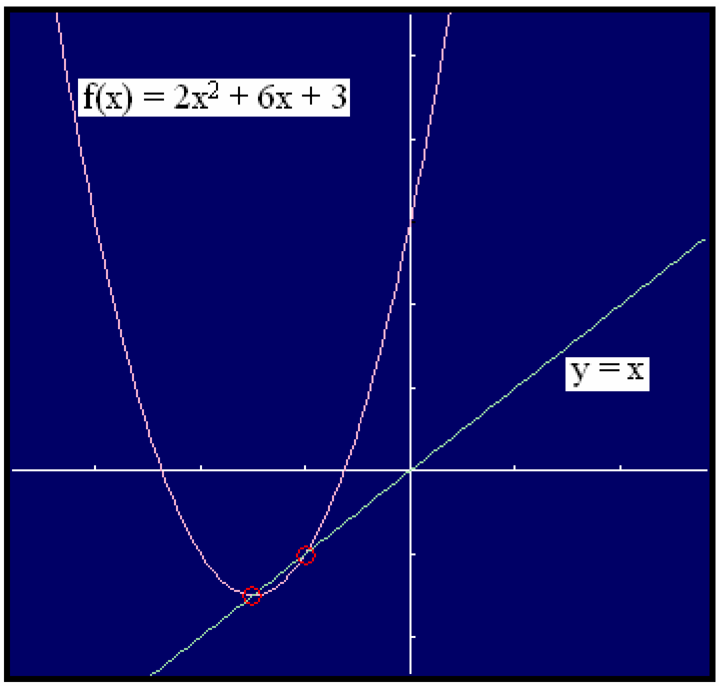


Figure 1.16. *Graphical visualisation of two fixed points under function f(x).*

2.5.4.3 Periodic Orbit:

This type of orbit (also known as a cyclic orbit), is where the trajectory can take several different values, which eventually loop back to the initial seed. Therefore the cycle continues infinitely. Formally this can be written $f^n(x) = x$, where *n* is the length of the cycle.

Example: $f(x) = 3x^2 – 7$

Given f(x), we can find an orbit with a period of two, through $f^2(x) = x$. Therefore:

$f(x_0) = 3x^2 - 7$
$f(x_1) = 3(3x^2-7)-7$
$f(x_1) = f^2(x_0) = x$:
$3(3x^2-7)^2 - 7 = x$;
$27x^4 - 126x^2 + 140 = x$
$27x^4 - 126x^2 - x + 140 = 0$

$x = -5/3,\ 4/3,\ 1/6(1\pm\sqrt{(85)})$

Taking the solution 4/3, we see that seeding it into the function f(x) results in an orbit which oscillates between the two values -5/3 and 4/3.

2.5.4.4 Attractors and Repellers:

There are two different types of fixed point orbits: attracting and repelling. (This is also true of periodic and eventually fixed orbits, but as they are unrelated to my system, I shall omit detail here). This section shall look at these types, and how they effect the dynamics of points within the neighbourhood of the fixed point. Let us take the function $f(x) = x^2$. This has two fixed points at 0 and 1. I shall look at the direction of convergence/divergence in the vicinity of these fixed points.

	n =Number of Iterations of $f(x) = x^2$					
Seed Value	n = 1	n = 2	n = 3	n = 4	n = 5	$n \to \infty$
0.1	0.01	0.0001	1x10^(-4)	1x10^(-8)	1x10^(-16)	→ 0
-0.1	0.01	0.0001	1x10^(-4)	1x10^(-8)	1x10^(-16)	→ 0
0.9	0.81	0.656	0.43	0.185	0.034	→ 0
1.1	1.21	1.464	2.144	4.595	21.11	→ ∞

Furthering my work in section ‘Graphical Analysis’, we can gain further information about the nature of fixed points, through the following procedure.

1) Start on the diagonal (y=x) at x_0 (the seed).
2) Draw a vertical line to the curve.
3) Draw a horizontal line back to the diagonal, and repeat the process.

This gives us a visual indication of the effect of successive iterations on any point. From the table above and the graph in Figure 1.17, it is clear to see that all points in the range $-1<x<1$ converge to the fixed point zero. Therefore it is an *attractor*. Contrariwise, points in the vicinity of the fixed point x=1 are all repelled away: When x>1, x diverges to infinity, and where x<1, x converges to zero. It is therefore a *repeller*.

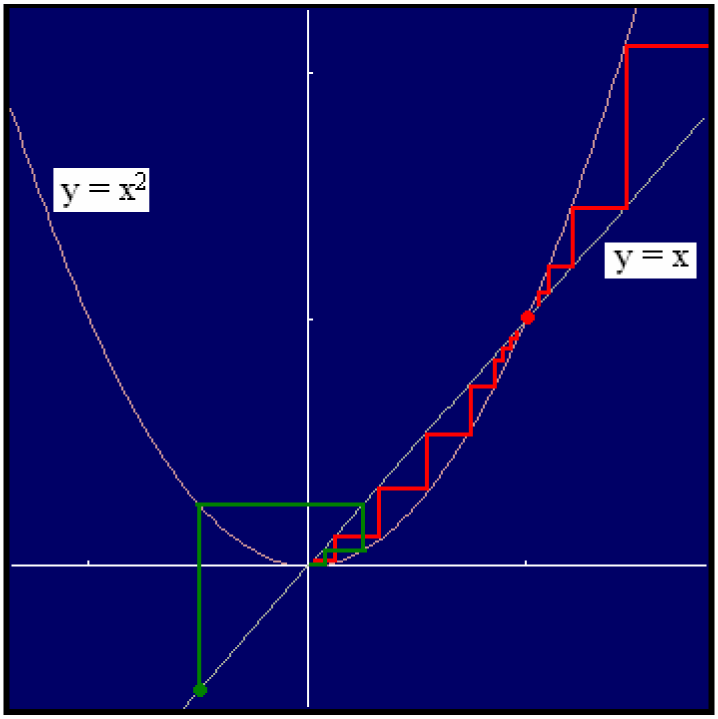


Figure 1.17.
The graph of f(x) = x^2 and three orbits. Those seeded at 0.9 and -0.5 are attracted towards x=0, whilst the seed at point 1.1 is repelled away from x=1.

There is a simpler way to determine whether a fixed point is an attractor or a repeller. The *derivative* of the curve at the intersection point tells us that:

For any function F: $\boldsymbol{R} \rightarrow \boldsymbol{R}$

$|F'(x)| < 1$: The fixed point is an attractor
$|F'(x)| = 1$: The fixed point is neutral
$|F'(x)| > 1$: The fixed point is a repeller

Fixed points and attractions to them can become a problem in some systems, in which it might be necessary to eliminate them. For example, in a complex system, there are so many agents interacting and spreading their influence in different ways, that unintentional fixed points can arise which leads to an unwanted convergence of the system.

On the other hand, considering an attractor in the context of human dynamical systems, it could be used to model the effect of children imitating the parents – i.e. 'the apple doesn't fall far from the tree'. A child could have many attractors however, which would thus eliminate clone-like behaviour. Repellers could be used in a similar way: e.g. on a grander scale, it could model a society moving away from a certain cultural value. Going back to fixed-points, this could model an individual who is extremely insensitive to the outside environment (i.e. in terms of a traumatized individual, someone who has cocooned themselves from outside invasion). A periodic point could model the steady behaviour of an individual stuck in a routine, or the daily attempts of a narcissist trying to extract supply (cf. attention) from other individuals.

It is clear that the study of orbits has a wide range of application in dynamical systems. One final point regards the transition from a stable orbit to an irregular one: the conversion from predictability to chaos.

2.5.5 Chaos Theory and Bifurcation Junctions:

What exactly is chaos? It acquired its name from the apparently disordered nature of the systems that chaos theory attempted to describe; though in fact chaos theory is really about finding underlying order in apparently random data. It describes the behaviour of non-linear dynamical systems, that under certain conditions display dynamics which are sensitive to initial conditions.

Because of this sensitivity, the evolution of these systems appears to be random/chaotic, because of an exponential build up of errors from the initial conditions; even though the system may be completely deterministic, i.e. no random elements are involved.

It was a meteorologist in 1960 called Edward Lorenz, who first truly experimented with chaos, and discovered the concept of the butterfly effect. At the time, he was working with a set of twelve equations which were supposed to predict the weather. He wanted to re-simulate a certain pattern (which he had printed off earlier), so he re-entered in his previous values. However, when he returned, he found that the system had evolved to become wildly different from the results of the previous simulation. He realised that the print out had rounded his values to 3 decimal places, which by all conventional opinions at the time should have made stark difference: such a small amount of difference in a measurement could be considered background noise, experimental noise, or be due to inaccurate equipment. However, the results were in accordance with modern chaos theory. Minute changes in initial conditions drastically changed the long-term behaviour of the system.

> The flapping of a single butterfly's wing today produces a tiny change in the state of the atmosphere. Over a period of time, what the atmosphere actually does diverges from what it would have done. So, in a month's time, a tornado that would have devastated the Indonesian coast doesn't happen. Or maybe one that wasn't going to happen, does.
> **(Ian Stewart, *'Does God Play Dice? The Mathematics of Chaos'*)**

Examples of situations which have basis in chaos theory include thermal convection, the simple flipping of a coin, and the dynamics of satellites in the solar system. The example I am to present relates to ecology, and the population dynamics of mice.

2.5.6 Predator-Prey Model:

In this closed system, there are two species operating concurrently: mice and cats. When the population of mice increases, the cats have more food and hence their population also increases. This rise results in more competition for food, and hence the number of mice decrease. With less mice to eat, the cats begin to starve, and their population decreases.

This cyclic behaviour can be modeled with a logistic function:

$$\chi_{n+1} = \mu \chi_n (1 - \chi_n)$$

This shows the population of mice at year *n+1* (i.e. χ_{n+1}) to be affected by two opposing trends:

1) A growing factor (μ) represents the rate of reproduction which must be proportional to the current population (i.e. $\mu \chi_n$)
2) A decreasing factor which relates to the theoretical carrying capacity of the population (a limit to their population size due to overcrowding and cat hunger): $\mu (1 - \chi_n)$.

It is easy to see how chaotic behaviour can arise from seemingly simple equations, if you consider the first few iterations of this function:

$\chi_1 = \mu \chi_0 (1 - \chi_0)$
$\chi_2 = \mu^2 (1 - \chi_0) \chi_0 (1 - \mu\chi_0 + \mu\chi_0^2)$
$\chi_3 = \mu^3 (1 - \chi_0) \chi_0 (1 - \mu\chi_0 + \mu\chi_0^2) (1 - \mu^2\chi_0 + \mu^2\chi_0^2 + \mu^3\chi_0^2 - 2\mu^3\chi_0^3 + \mu^3\chi_0^4)$.

We find that by varying the growing factor, we obtain radically different results in the system.

For example, with $\mu = 2$, and x intialised as 0.25, the first few iterates are:

{0.25, 0.375, 0.46875, 0.498047, 0.499992, 0.5, 0.5, **0.5**, ...};

This orbit reaches a fixed point of 0.5.

For $\mu = 3.2$, the iterates are:

{0.25, 0.6, 0.768, 0.570163, ... , 0.799455, 0.513045, **0.799455, 0.513045**, ...};

This orbit eventually oscillates infinitely between the last two values.

For $\mu = 3.46$, the list of iterates are

{0.25, 0.64875, ..., 0.838952, **0.467486, 0.861342, 0.413234, 0.838952**, ...}, These last four values repeat infinitely in a 4-period cycle. This phenomenon of period-doubling is called *bifurcation*.

<u>We can classify the different regions of this model:</u>

$0 < \mu < 1$ → Population extinction, orbit decays to 0.

$1 < \mu < 3$ → Stabilises to fixed point of $|(1-\mu)/\mu|$

This can be shown using our criterion for a fixed point with the logistic function:

$$F(\chi) = \chi$$
$$\mu\chi(\chi - 1) = \chi;$$
$$\mu\chi^2 - \chi(\mu-1) = 0;$$
$$\chi = [\ (1-\mu) \pm \sqrt{((1-\mu)^2)}\ ] / 2\mu$$
$$\rightarrow \chi = |(1-\mu)/\mu|$$

$3 < \mu < 3.45$ → Population oscillates under a periodic orbit infinitely (period = 2).

$3.45 < \mu < 3.54$ → Population cycles under a periodic orbit, (period = 4).

$3.54 < \mu < 3.57$ → Population cycles under a periodic orbit, (period = 8).

As μ increases, the period of the orbit continually doubles (i.e. from 8 to 16, 32, 64…etc), tending to infinity. This can be summarized effectively in a bifurcation diagram (see Figure 1.19).

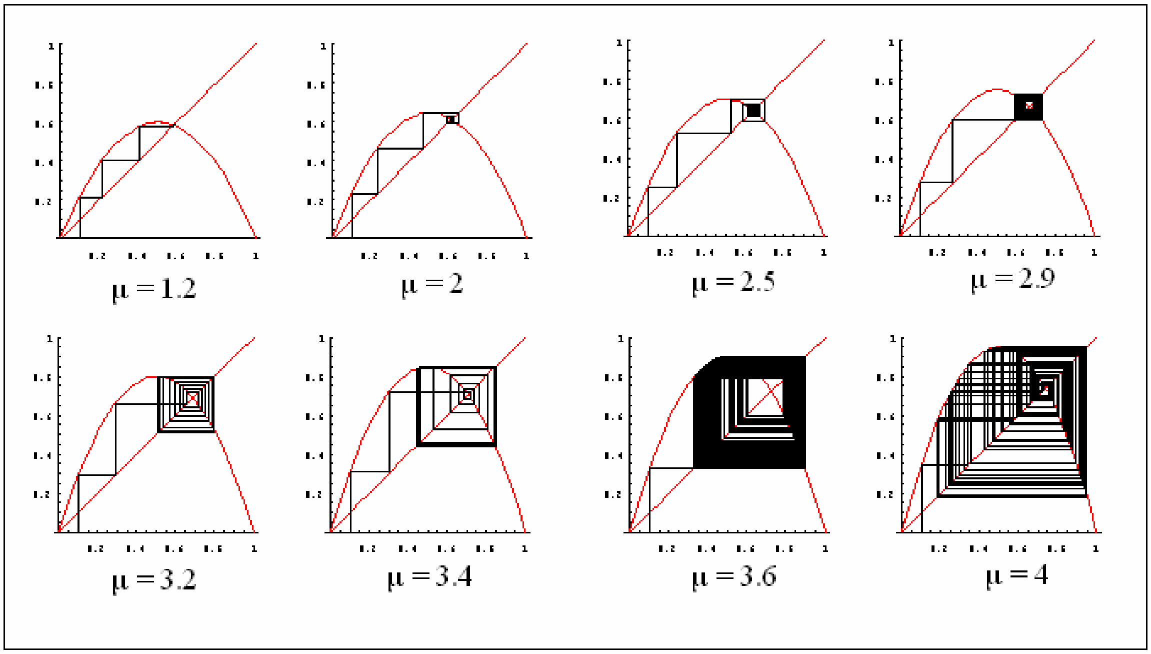


Figure 1.18.

Graphical analysis of the logistic function,for varying values of the growth factor (μ). For low values of mu, there is a single fixed point. As mu increases, we get a series of periodic points which increase in magnitude very rapidly, leading to the chaotic system of >3.54.

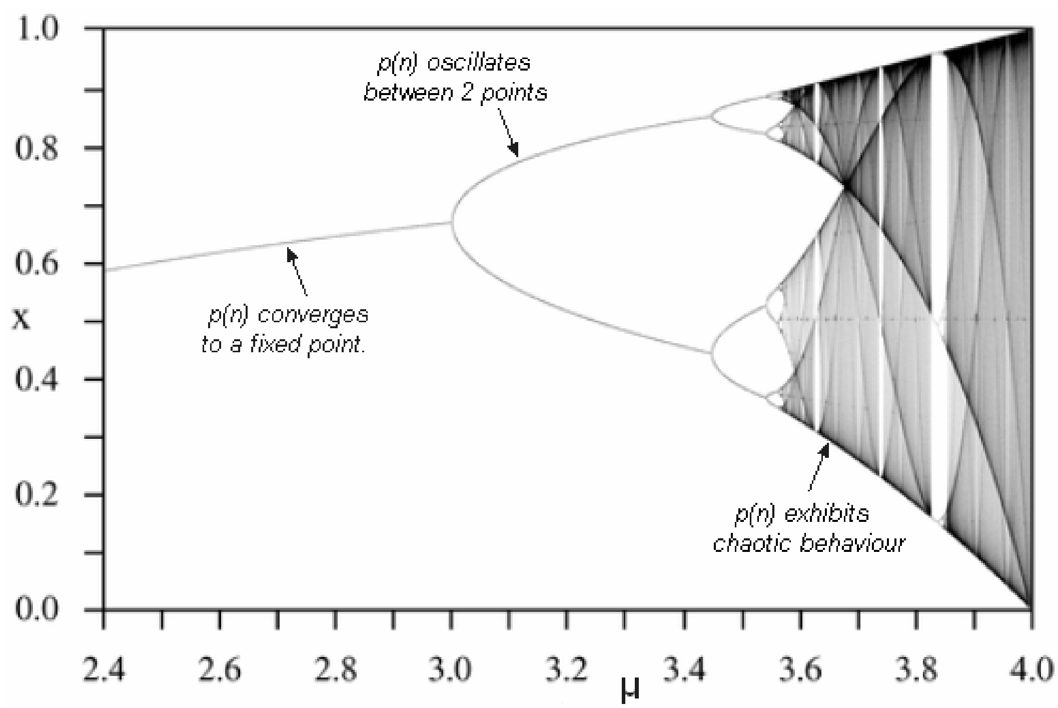


Figure 1.19.

Bifurcation Diagram, plotting as a function of the growth factor (mu) the series of values x(n), obtained by assigning x(0) a random value then iterating many times, discarding those iterates before an attractor is reached. Hence, p(n) indicates the current population of the system at time n = infinity. The branches represent bifurcation junctions.

With a periodic orbit tending towards infinity, the system jumps incessantly among an infinite number of values in a way which – though deterministic – cannot be predicted over a long period of time. It descends into a regime of chaotic behaviour. This effect of the logistic function can be seen pictorially in Figure 1.18.

If we look at μ=3.85, we can observe a small window of stability, where the mice population ascends back into an ordered periodic cycle. This phenomena is known as *intermittency*, since it represents a period of order within total chaos. We could therefore consider that deterministic behaviour is simply a subset of chaotic behaviour, and it is possible to extract order from chaos. In essence, this is comparable to the search for emergent behaviour from a complex system.

Finally, notice that the bifurcation junction is a critical point – i.e. the edge of chaos, as discussed in section 2.5.5). A small change in the system could push it into chaotic or ordered behaviour. This could be used to model an individual on the brink of an emotional break-down – i.e. counseling might unwind the situation, whereas an unkind word could push his mental system into disarray.

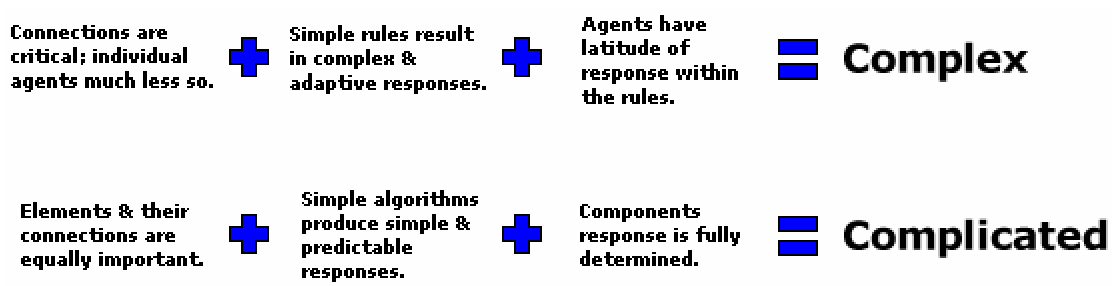
The deterministic chaos prevalent in this system reveals the importance of fine-scale details on the large-scale behaviour of a dynamical system. However, what happens when we look at a stochastic dynamical system? This area is known as *complex systems*.

2.6 Complex Systems:

"Complexity is about how a huge number of extremely complicated and dynamic set of relationships can generate some simple behavioural patterns, whereas chaotic behaviour, in the sense of deterministic chaos, is the result of a relatively small number of non-linear interactions." - (Cilliers, 1998).

Essentially, a complex system arises when we have a number of distinct components interacting in a non-linear way. Acting non-deterministically, there is no way to predict the evolution of the system.

It is important to underline the distinction between complicated and complex systems. Cars and computers are examples of the former, where there is a variety of interacting parts which do so with complete predictability; whereas with complex systems, agents have *freedom of decision*. The function $x_{n+1} = f(x_n)$ may not product the same results on different runs, because agents in the system have a latitude of response within the rules, meaning there is a probabilistic element to their motion. "*The emergence of complexity theory shows a domain between deterministic order and randomness which is complex.*"



2.6.1 Examples of Complex Systems:

There are many examples of actual complex systems all around us.

- Ant hills
- Human economies
- Climate changes
- Nervous Systems
- Motion of satellites in space
- Movement of bird swarms

Examples of complex social systems:

- *A Business Organisation:*
  A major factor every manager should take into account when considering the success of their organisation, is their ability to reduce vulnerability to the

environment. This requires an ability to predict future states of the environment so that self-organisation and preparation can take place. However, there are so many factors which affect the environment (from the actions of colleagues, competitors, current trends, the economy) that accuracy in these predictions is impossible. The unpredictability of the environment renders it a complex system. Therefore, with this in mind, managers should be regarded as facilitators for change rather than controllers (since it is not possible to utterly control every aspect of the organisation).

Changes in environment can be considered a bifurcation junction. Either the organisation responds appropriately and regains ordered behaviour, or it disintegrates from market pressure. By altering the current situation (through office culture, missives, and charm) the manager may be able to direct the complex system by introducing *change* (i.e. second order emergence), through new working practices and self-organisation.

- *A Family System*:
  Craig Chalquist's study on complexity and the family structure[URLc], is an account of the complex nature of the psychosocial interactions which occur within a family system. For instance, consider the levels of structure within a simple family unit. We have the *executive subsystem* that is the parents, and the *sibling subsystem* of the children, and related to each (and the connections between the two) we have a loose set of rules. These are 'designed' to stabilise the family, in different ways depending on the subsystem. For instance, it has often been noted by psychiatrists that during family counseling sessions, when the parents are asked something which makes them feel uncomfortable, the child will often act out, or behave in some way which distracts attention away from the parents. This happens on a subconscious level, but nevertheless, this stabilising action acts as self-protection of the family unit.

  According to Chalquist, a common family problem is a weak boundary between subsystems. Consider an over-zealous mother who instructs her offspring in every aspect of their life – from their behaviour, to their clothes. This authoritive parenting is something I shall be exploring in my model, since it can often breed narcissism in a child.

  One final example of the complexity of actions that exist within a family system is more extreme, though not altogether uncommon. Consider that one member of the family is an alcoholic. His behaviour is bound to affect the rest of the family; with bad health, erratic behaviour, potential poverty and even violence. The family is likely to *mal-adapt* itself to the alcoholic's behaviour, by lying (perhaps to their friends or their boss), denial of the situation, learning to not absorb angry behaviour, and perhaps even the unconscious nomination of a child to act as a father-figure, or beacon of responsibility. These are negative changes which lead to dysfunctional behaviour, but again we can see the fluid adaption to both internal and external stimuli.

Examples of artificial complex systems:

- Cellular automata (e.g. modelling bird swarms – *Boids*)
- Evolutionary computation (e.g. genetic algorithms)
- Particle dynamics (in 3D space).

2.6.2 A Closer Look at Complexity:

Historically, the notion of complex systems was discovered by the 19th century mathematician Henri Poincaré, in response to a challenge set forth by Oscar II, King of Norway and Sweden: to forecast the evolution of a causal system of three disparate entities. This is commonly known as the *3-body problem*. Poincaré decided to work on equations used to predict the trajectory of planets, though found that even for a system as simple as the non-linear interaction of three planets, it was impossible to predict their evolution. Though this conjecture was revolutionary, its consequences were not fully appreciated until the advent of the computer – where advanced simulation proved the staggering implications of his work. Poincaré had predicted chaotic motion and complex systems.

In reality, we find that many different layers of complexity exist, even in apparently simple objects. Their internal structure consists of a wealth of diverse and complex behaviour, which is evident when you consider the solar system – and yet, these microscopic details are somehow not relevant on the larger scale. Consider the relationship between a galaxy and its elementary particles. Galaxies are composed of stars, which in turn consists of complex plasmas. They are orbited by planets which are formed from a diversity of materials, and even living organisms. These, in turn, are formed from atoms, which can be broken down further into subatomic particles in the form of quarks. With all these levels of complexity, we can still measure the state of a grander system, forgetting these smaller-scale details (consider Kepler's laws of planetary motion).

It is therefore possible to model a system without losing too many of its properties, by *simplification*. With a few relevant parameters (which arise from the microscopic description), we can describe the macroscopic behaviour of physical systems, losing much of the irrelevant microscopic details. The approach of *scaling* and *renormalisation* attempt to discover which of these parameters are significant to the large-scale problem, in order to simplify its analysis.

Thus, the essential question to myself, as the creator of a socio-technical system, is: *to what extent can we abstract from microscopic interactions, in order to understand the macroscopic behaviours?* For instance, is it necessary to model the limbic system of my agents (i.e. the emotional control centre of the brain)? Or could I abstract away this complex system, and convey their entire emotional scope with several parameters representing individual emotions? Over-simplification of models can lead to unrealistic results.

Finally, from an epistemological and methodological point of view, we are left with an important question. *Will structured emergent behaviour be explainable by local rules of interaction*? My job as system creator will be defined by these two important questions. In the next section, I will convey my decisions for the levels of abstraction, and attempt to relate macroscopic behaviour back to its microscopic beginnings.

2.6.3 Properties of Complex Systems:

2.6.3.1 Non-Determinism:

By definition, a complex system is non-deterministic, since it consists of a number of elements interacting in a non-linear fashion. It is easy to see how this creates chaotic behaviour, and an inability to predict the system's evolution. This lack of tractability can play a useful role in the broadcasting of information from an individual to a collective; since in this way, societies are formed.

2.6.3.2 Limited Functional Decomposability:

Some complicated systems can be completely described as the sum of its parts – which is formalised with systems theory: the calculation of global operation based on individual elements. A simple example is the operation of a motor: one cog turns the next, causing a predictable chain reaction of events.

A complex system on the other hand has a dynamic structure which continuously changes based on many factors, including external events and internal changes. Consider the division of labour in a 'social' insect like the ant. Workers have specialized jobs, though these are not rigidly adhered to. Depending on changing conditions (see Figure 1.20) the ants will switch roles in order to maximise the success of the colony and its reproduction rate. For instance, we know that ants travel in almost single file along a bypass which minimises travel-time to a food source. It was very recently discovered that if an ant found a hole in the bypass which impeded progress, it would switch tasks and act as a living bridge for the other ants[URLd].

In the context of human dynamics, a person will display a diverse range of behaviours during interaction, depending on their relationship to the other agent. Children grow up receiving orders; but eventually they may become parents themselves and have to issue orders in turn. There is the capacity for rapid reorganization in the functional structure of a socio-technical system.

It is precisely this instability in the nature of a complex system which attributes it limited functional decomposability. The fluctuating character of its constituent functions means it cannot be represented by a collection of functionally stable components.

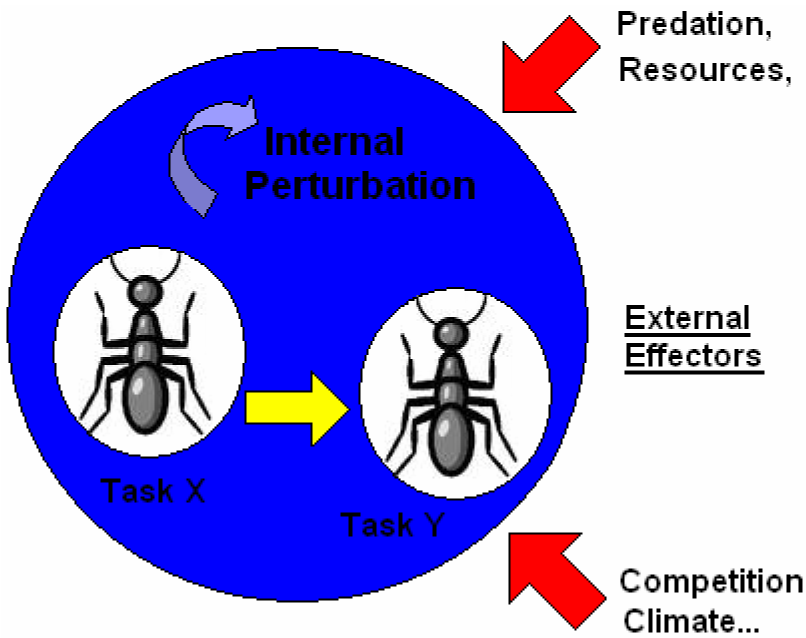


Figure 1.20.
Self organisation mechanisms imply a structurally unstable system.

2.6.3.3 Distributed Nature of Information:

A complex system is comparable to a distributed system, since its resources are spread over many different sites (i.e. agent locations). By resources, I mean knowledge of the system. Information travels through short non-linear relationships, and in this way, a complex system is robust, since even after an event of mass-traumatisation (say half the population is destroyed), the distribution nature of information means that state is not completely lost. The system has the ability to re-stabilise.

2.6.3.4 Emergence:

Perhaps the most significant attribute of complex systems is its ability to display *collective behaviour*, in the form of new and coherent structures or patterns. Nothing in the system commands the formation of these patterns of global behaviour; rather it is the interaction of its elements which result in order, via a complex chain of events. In other words, micro-level interactions lead to emergent phenomena observable at the macro-level.

In the context of human systems, we could consider the convergence of a society to a cultural norm (attractor) as emergent behaviour – or the segregation of a society into different partisan groups owing to the dynamics of strong leaders.

It is important to note that human society exhibits a very different kind of emergence than do other complex systems. Non-human social organisations (e.g. ant colonies) do not have the ability to reason, and are therefore unaware of emergent behaviour developing.

Humans, as sentient creatures, have the ability to recognise emergent behaviour – and therefore they can react to it. This *iterative feedback* gives rise to the more complex class of second-order emergence.

A good way of describing the system is by studying its collective behaviour. It can show the major attractors/repellers of the system, and if the results are relevant to the problem at hand, it can verify the assumptions made in your model.

2.7 Modelling Packages.

A multi-agent system (MAS) consists of a collection of autonomous entities, who interact with each-other in virtual space, similar to the behaviour found in cellular automata (the chief difference being that MAS allow agents a higher degree of freedom, with no restrictions to local neighbourhoods). Agents are endowed with rules which govern their interaction with the environment and with other agents, and over time they evolve (often with no human interaction required). A MAS can be used to model anything from particle dynamics to the socio-cognitive interactions of human agents.

However, these systems generally have a number of similar features, which is why several platforms for agent-based modelling have been created. I shall be considering the three most celebrated MAS platforms: Swarm, Ethos, and Repast. I shall judge them based on a number of factors, including:

- **Support for modelling & simulation control** (does it contain procedures for common theoretical-content modelling?)
- **Extensibility/Modifiability** (will it impose constraints regarding attempts to expand the platform past its current capabilities, and will it be possible to alter the platform's base implementation?)
- **Robustness** (can it give accurate and reliable results at critical points during a simulation?)
- **Future viability** (is the model out-dated? Will the platform still be available for other users in the future?)
- **Ease of use** (how much technical overhead is there to learning the simulation package library?)
- **Support & Documentation** (is the platform well-documented?)

2.7.1 Swarm:

This was originally developed in 1994 by Nelson Minar and Chris Lanton at the Santa Fe Institute, specifically for simulating multi-agent complex adaptive systems. It is the most famous and widely used MAS platform, and has been used to model systems from many different fields: from physics to economy and ecology.

This system consists of *swarms*, which are collection of agents. The entire model is represented by a swarm, and the agents themselves can also be composed of swarms. This hierarchical structure is therefore suitable for modelling a layered system; for example, a business organisation consisting of departments and employees. Agents operate under an Activity Framework, whereby they maintain a schedule of events, which they trigger at the appropriate times.

An interesting feature of Swarm is the Observer swarm; an external agent who can make modifications to the entire system – independently of the actions of internal agents. This provides a powerful method of non-intrusive control. Other features include Information Probes (to easily extract information from the system), Memory Management, and a powerful GUI which allows easy input and the extraction of statistical output. However, the GUI has severe limitations in extensibility, which can become a problem when dealing with non-standard data.

Swarm provides comprehensive documentation, and is being continually developed by the Swarm Development Group. It runs on any platform, but has a steep learning-curve, owing to many swarm-specific ideologies and commands.

Swarm can be downloaded at (http://www.swarm.org./wiki/Swarm:_stable_release).

2.7.2 ETHOS:

Despite being the youngest of the MAS platforms, ETHOS has many special features which places it above the others. This conceptualised framework is specifically designed to model *human* multi-agent systems, with a variety of constructs for easing the implementation of common human interactions.

It provides a meta-model which allows the user to instantiate classes based on the human social behaviour they wish to represent. This include abstractions of individual and collective social behaviour, the dynamics of culture, and emergence of social structures. It provides support for drives, behaviour selection, transmission of information, encoding of agents with genes for reproduction, as well as management of the agents' social networks (including distinguishing parent/offspring and professional relationships etc).

Along with these highly relevant features, it also provides a standardised GUI output, and allows data exporting; so that data objects can be analysed in specialised data analysis and graphing programs such as GunPlot.

It's high level of abstraction suggests a shallow learning curve in terms of the intricacies of each functional component, though a good level of knowledge of the capabilities of the overall system would be required in order to exploit the additional features of this framework.

On the negative side, documentation for ETHOS is limited, with very few working models available for testing. Development of this framework has also been discontinued.

2.7.3 Repast:

The Recursive Porous Agent Simulation Toolkit (Repast) is an open-source toolkit developed by Sallach, Collier and Howe at the University of Chicago, which seeks to support the development of flexible models of social agents; and in essence is an extension of Swarm.

This framework includes a fully concurrent discrete event scheduler, which supports sequential and parallel operations, and it also provides a range of agent environments and visualisations. Among its features are a variety of libraries for supporting neural nets, adaptive regression models, but interestingly none for the creation of agents.

Currently, the framework operates under Java only, and is hence platform-independent. Repast is still under ongoing development, providing extensive documentation, and receiving a high level of support from the academic community of social-sciences.

Repast can be downloaded at: http://repast.sourceforge.net/download.html

2.7.4 Conclusion:

I have decided to implement my system in *Java*. This will allow me the modularity of an object-oriented language, necessary in a model consisting of such functionally distinct components. The language is user-friendly, platform-independent, and can be easily converted into an applet for internet release.

The MAS platform I have decided upon is Repast. I chose not to use Swarm because its interface left a lot to be desired, and it wasn't flexible enough for my needs. ETHOS on the other hand was perfect for my particular project, since it dealt so explicitly with many aspects of the human condition. However, with no demonstration systems to test for reliability, and a lack of documentation, it was a risky course of action.

Repast was my final decision because of its lack of restriction upon extensibility and modification. It puts no limitations on the agents in your system (including nesting of agents), and allows you to build a simulation to your exact specifications. Initially I began work on my model using a new variant of Repast called Simphony (a visual development environment), of which I spent some time during the early stages of my project helping the Repast developers to release a working version. Screenshots of this early model are shown in Figure 1.21 and Figure 1.22. However, discovering it to be fairly constrictive, I continued with the original version of Repast.

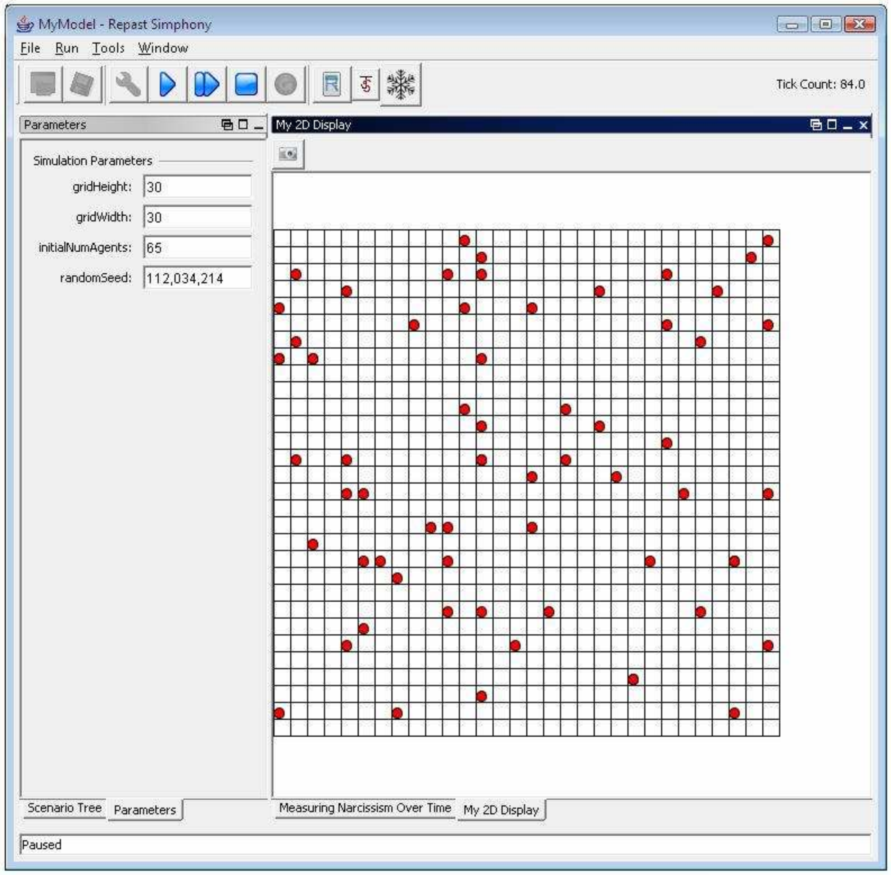


Figure 1.21 *State-space containing agents in my original Repast Simphony model.*

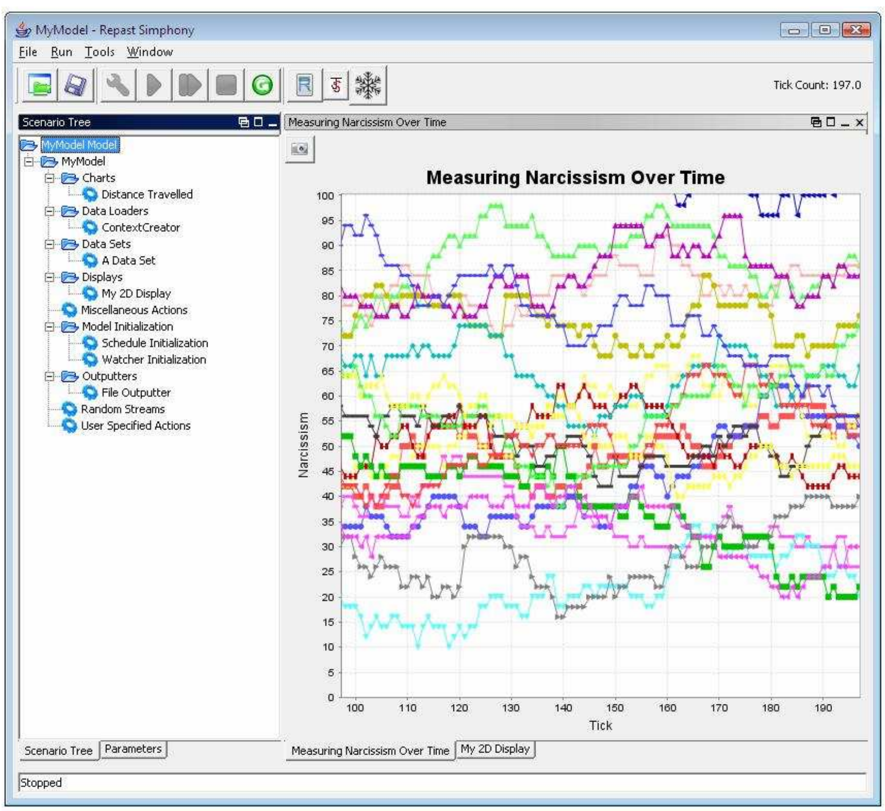


Figure 1.22. *Measuring narcissism in my Repast Simphony model.*

3. Description of the Model

3.1. Introduction:

My model aims at representing a society of human individuals, similar to that found in any part of the world. The basic human dynamics of a society are very similar in both primitive tribal clans of the past, and what might be termed the civilised societies of modern Eastern and Western culture.

There are, however, some differences which I have abstracted away, to create an independent, generic society. For example, I have eliminated preconceived gender stereotypes and ageisms which are more prevalent in some societies than others. War, poverty and class distinctions have been removed, in order that this model can concentrate on the universally applicable subtleties of human interactions, which differ based solely on relationship.

The model comprises of a city, which consist of a number of households. A household contains a number of human agents, synonomous to a family. Agents in this society interact on a one-on-one basis, with family members and external agents based on the mental parameters of the agents in question. They react differently based on emotion and mood. In this way, we can consider the simulation to be a complex system.

There are other factors which affect reactions to any given situation, which include past relationships with agents, and their particular type of association with that agent (consider how a child might react differently to a fight with a friend, compared to the same interaction with a parent…one can be a lot more damaging).

Agents are born, they go to school, they leave home and try to find a mate, they get jobs, they have children, and they die. The overall structure of an agent's life is very similar throughout the model, though the emotional health of an agent and the affect on those surrounding it can be dramatically different.

In my model, I have taken this into consideration, by looking specifically at how interactions with the family can alter the character of a human agent, and the repercussions this has during their life. It explores questions relating to the fundamental essence of a human being, and from where their character is derived. For instance, is personality a hereditary thing, and if not where does it develop? At what stages in an agent's life does the ultimate question of who they will become get decided – where is the bifurcation?

This is a question which has been the subject of great debate throughout the academic worlds of social-science and psychology. I have explored this question in part through the study of narcissism. By following this severe emotional template, and the unique breed of human it creates, I have attempted to model its birth and its spread; thus determining and classifying the family's pervasive influence.

3.2 Model Overview:

The model I have created is an object-oriented multi-agent system, where agents interact on a 2D toroid grid. The agents are simple abstractions of human beings. Their positions on the grid are relatively stable (only changing when moving to a different house), though they perform simulated encounters with different agents and different neighbourhoods of agents depending on the situation.

For example, during the 'work' or 'school' phase of an agent's regular routine, they will interact with agents who may not be in the immediate Moore neighbourhood of their home. A virtual framework for an office or school is created, which is populated by eligible agents within a preset vicinity, decided upon by a variety of factors. Whilst at home, they can spend some time interacting with neighbours, and of course with family members within their own household (consisting of partner, children, and siblings, if applicable).

A human agent is represented by a number of parameters, which include "Integration", "Awareness" and "Ego". The actions an agent decides upon are directly related to their levels for these parameters, along with a number of factors dependent on their relationship to the other agent. For the most part, these factors vary between -1 and 1, and their meanings are (inversely) symmetric around 0.

- **Awareness:** This parameter represents how aware the agent is about themselves and how objectively they understand their environment. An agent with a high level of awareness will understand his fellows, be well educated and have the ability to pass on information. The other end of the scale is Indoctrination, which correspondingly means the agent will not understand their own emotions, and can easily be manipulated due to a lack of understanding of the world.
- **Integration:** This represents the emotional maturity/health of an individual. The two extremes of this parameter lead to an integrated agent, and a traumatised agent. The former would be well integrated into society, having no trouble with their emotions, while the latter would be troubled and often unhappy, unable to cope with the past or present.

These two parameters relate closely to the two halves of a human brain. The left side is the analytic section of our brain, corresponding to awareness. The right side is the emotional section, thus corresponding to integration.

- **Ego:** This is a subtle, though important parameter. This represents the agent's level of self-esteem (or self-love). Because I am dealing with very subtle human emotions in this model, I have separated this from integration level, making the two mutually exclusive. Consider an individual who has returned from a long and bloody war. The things they have seen may well have completely traumatised them, but their levels of self-love are unchanged. This parameter varies between 0 and 1, and actually performs a dual purpose significant to the subject of narcissism. This shall be explained in further detail later.

- **Other factors:** An agent's ideals are represented, along with specific attributes like the level of attention they've received, how authoritarian they are, and their strength, etc.

The agents decide how to interact considering all of these factors (and more that are related specifically to individual relationships). Agents are either passive or active in these interactions – i.e. if the active agent decides to talk, the passive agent *has* to listen and give a reaction to the communication. The choice of interaction and the *re*action alters both agents' mental states, and their current relationship. An agent can choose to:

Talk and **Compliment**	→ These are pro-social interactions which consolidate relationships.
Ridicule and **Fight**	→ These are anti-social interactions with a variety of negative effects.
Lie and **Request Attention**	→ These are used by agents who, for their own reasons, have a need for attention.
Teach	→ This is a neutral interaction, whereby an agent attempts to enforce their beliefs on another agent.

The reasons behind my decisions to use these interactions will become apparent later, when I look more closely at modelling a narcissist. (It should be noted that 'Request Attention' is an interaction used solely by babies, who at this stage are *classic narcissists*. Lying is often the resort of a *pathological narcissist*).

As the agents in my system evolve through time, there are a number of age-related considerations to be made. These lead to restrictions on abilities and actions that an agent can take (as was just demonstrated with the 'request attention' interaction). These classifications lead to the following chronological time-line of an agent's life, where an agent:

- Is a baby.
- Becomes a child, and goes to school.
- Becomes a teenager, and moves school.
- Finds their own house, and goes to work.
- Possibility of finding a mate, and getting married.
- Can usually have up to three children (though five is possible).
- Die.

There *are* variations on this theme, which include growing old enough to become head of the household, looking after your siblings, and abandoning your family and children.

My fundamental focus in this model will be *parent-offspring interactions.* Consequently, the childhood and parenthood stages of each agent are of most significance. By determining the treatment an agent received as a child, we can compare this to their treatment of their own children: thus showing the cascading effect, and allowing us to explore the generational spread of traits. In this way, my project is very different to others which model human dynamics. Rather than concentrating on the *horizontal* dissemination of information, between agents in any snapshot of time within the model, my efforts are driven towards the *vertical* spread of information (i.e. down the generations).

3.3 Frameworks:

3.3.1 The City

This is the highest level framework, all agents being encapsulated within it. The city consists of a 2D array of households, in the form of a torus grid. The size of the city is an editable parameter, so that any number of households can be displayed; however, by default its size is set to 30x30 = 900 households. Agents interact within households (see 'The Household'), their schools and offices (see 'The School and Office') and in their direct neighbourhood. This is in the form of a Moore Neighbourhood, as discussed in the section 'Cellular Automata'. A class diagram for the city is shown in Figure 2.1.

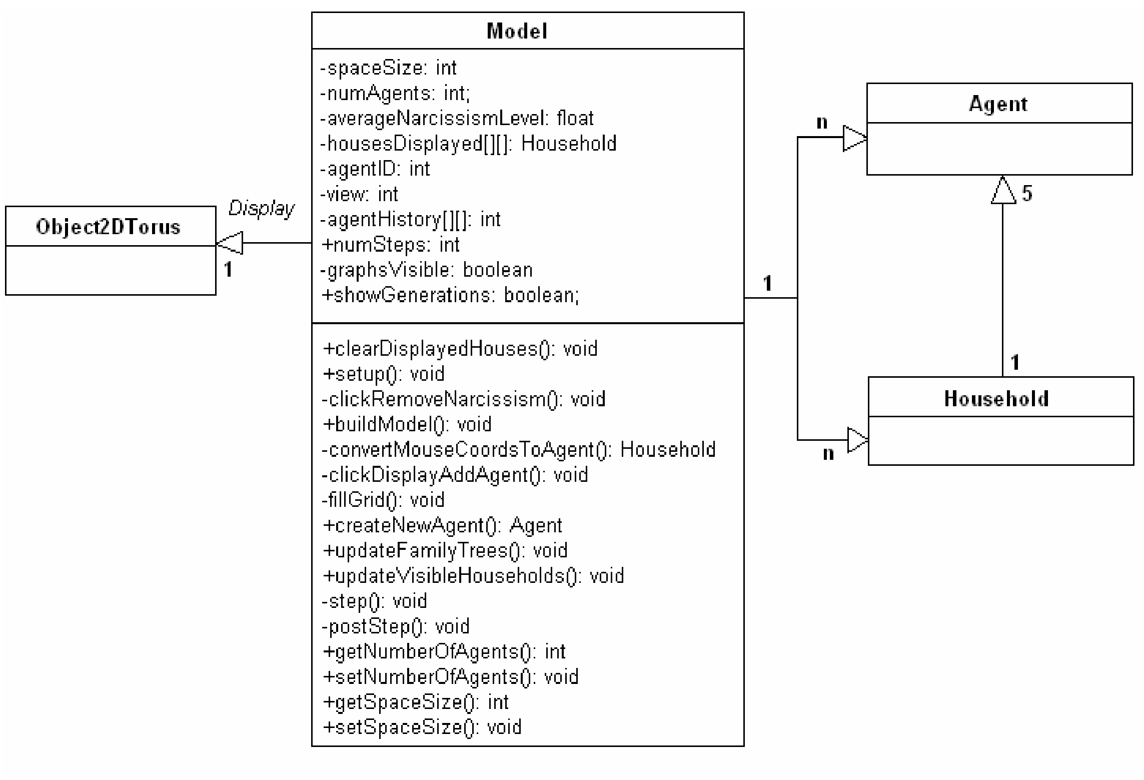


Figure 2.1. *UML Diagram of the Model Class*

I have omitted inputs from the diagram for the sake of brevity. As can be seen, the city consists of a number of households, which hold agents. The city has direct access to every single agent, since the city controls the scheduling of agent actions. It cycles through the arraylist of agents at every *tick* (i.e. single discrete time-periods within the model), calling their 'step()' methods. The model also has access to every household on the grid, because there are some actions which the model needs to perform on singular households; and therefore easy grouping of agents is accomplished by storing households as a separate entity. Due to the object oriented nature of Java, no extra memory is used; and quicker access is enabled. The Object2DTorus takes the household list, and uses it to draw the city, with each element representing a household. An image of the city is shown in Figure 2.2.

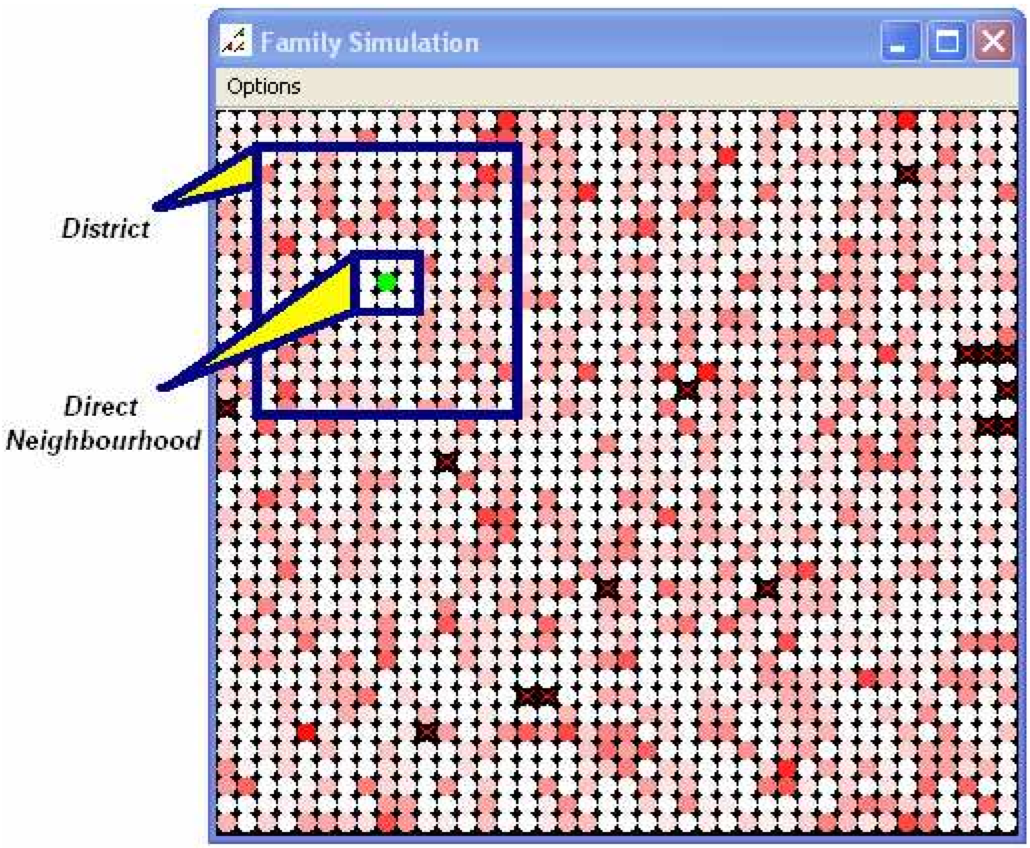


Figure 2.2. *The City Framework*

Each circle represents a household, which contains the agents. As shown in Figure 2.2, a household can interact with anyone in their direct neighbourhood: a short-range, linear relationship. This is equivalent to a Moore Neighbourhood of 1, though this is an editable parameter, so that the reach of a neighbourhood can be extended further. The district, as shown above, is where the population for the city's schools and offices are derived from.

3.3.2 Schools and Offices:

In my model, schools and offices are in fact abstract notions which correspond to a warped version of reality. The members of each household attend a school or office, whose attendees are ever so slightly different from the schools and offices of their neighbours. As you can see from Figure 2.3, the occupants of the green and blue houses attend the same school, since their districts overlap. However, the attendees of the blue house's school are slightly different from the attendees of the green house's school.

The reason I have made this distinction is twofold:

1) By allowing the user freedom to alter the city's size, this creates a problem. The size of the schools would either all have to change to fit the grid, or they could keep their sizes, and irregularly sized schools would have to be used to pad the edges. Neither of these solutions are ideal.

   It is a common scientific principle that in testing, only one parameter should be altered at a time – the rest should remain as control parameters. In this way, we can see the effect of changing the test parameter. However, this principle would be broken if altering the city size forced the alteration of school sizes or the introduction of irregularities.

2) This allows for gradual areas of interaction, rather than splitting the agent-space into discrete spaces. Consequently, a household's community is localised rather than regional: and this allows us to easily relate emergent phenomena to their points of origin.

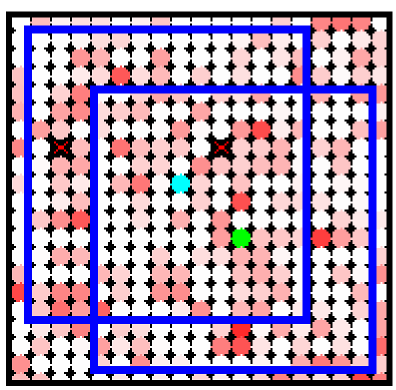


Figure 2.3.
School & Office Districts

The schools are split into classes, dependent on the ages of the pupils in question. Classes exist for students aged between: 300 & 500, 500 & 700, 700& 900, and >900. As a student grows older, they move between classes, and interact with people their own age. As an option, the user can also choose to segregate students based on their Awareness Levels. This is synonymous to grouping students based on intelligence rather than age: this is true of some areas of the world (including South America, and to a lesser extent the US).

Offices work by exactly the same principle, except they are split solely on level of Awareness. This allows people of higher awareness to interact on a regular basis, so that they are not continually frustrated by conversations which aren't to their level. Agents can be accordingly promoted and demoted based on their awareness level (and an element of probability).

> **Narcissism Remark:** *As a side-note, when considering narcissists, one must remember that they enjoy status symbols, and things to be admired. This can be based on trophies like cars and women, and also their job. Therefore, these distinctions in the workplace are important so that a narcissist can feel self-important, and the gap between their ego and their ego-ideal is diminished. This class distinction is especially true of cerebral narcissists, who prize intellectual prowess. This is modelled in my system, and shall be explained further in the section entitled 'The Agent'.*

Agents go to school until they leave home, and work in the office until they die.

3.3.3 The Household:

This is a very important framework, since a household contains the members of an agent's family. When an agent is born, the only people they know are in their household, and during their day-to-day actions, a large part of their interactions will take place within the confines of this locality.

A household contains at most five agents, with a maximum of two parents, and a maximum of three children. However, if a child moves out, another child can take its place (though each parent can only have a maximum of five children anyway, and the probability of this occurring is very low).

A UML diagram for the Household class is shown in Figure 2.3. As shown, a household contains a number of agents, and holds details about agents' positions within the household (i.e. parent or child). A household can be probed from the main screen, and can load a visual representation of itself using the Java Swing library. The HouseFrame class uses the agents' ability to draw themselves, and knowledge of their household roles to display the household to screen, as in Figure 2.4. The squares at the top contain the parents, and those at the bottom contain the children. In this example, the family consists of two parents and one child. Details of using the household to extract information from the system is discussed in 'Using the Model'.

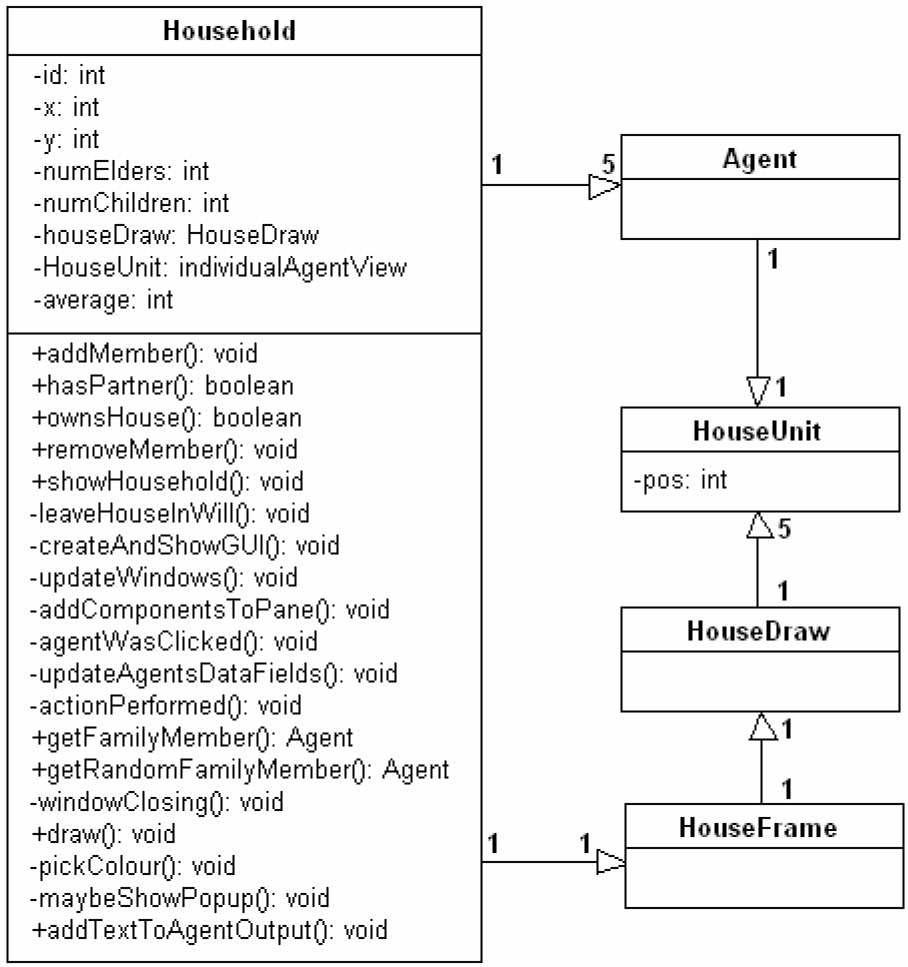


Figure 2.3. *UML Diagram for the Household Framework*

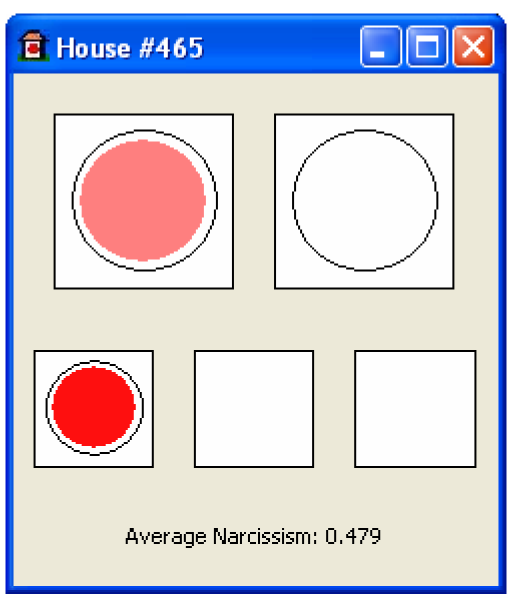


Figure 2.4. *The Household Visualisation*

3.4 The Agent

The frameworks described so far are containers for agents to act within, but the fundamental building block of the system, the *active* element, is the agent. (A screen shot of the agent visualisation screen is shown in Figure 2.4.1).

3.4.1 Agent Parameters:

As simple abstractions of human beings, the agents are defined by the following parameters.

- Id
- Sex
- Age
- Expected Time of Death
- Integration
- Awareness
- Ego
- Strength
- Aggressiveness
- Authoritiveness
- Cerebral Ideal
- Somatic Ideal
- Narcissistic Supply

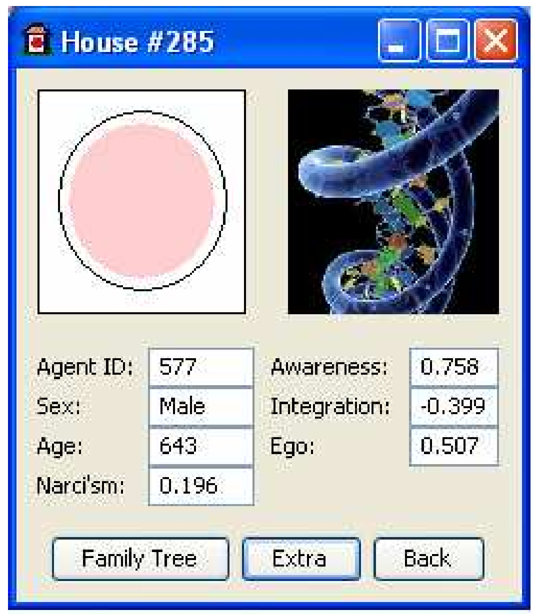


Figure 2.4.1 *Agent Visualisation Screen*

In fact, an agent holds many more parameters than those listed above, but many are related specifically to narcissism, and without further context, their description would make little sense here. Therefore, explanation of these further parameters are saved for the proceeding sections. I shall now describe the parameters listed above in more detail:

❖ <u>Id:</u>
Type: Integer
Range: Between 0 and infinity
Comments: This is a unique identifier for each agent. It is used solely as means of recognising and tracking agents.

❖ <u>Sex:</u>
Type: Boolean
Comments: The sex of the agent is set to female if this boolean is true, and male if set to false. This is used in finding partners, and discerning the validity of procreation.

❖ <u>Age:</u>
Type: Integer
Range: Between 0 and ~5000

Comments: Each tick of the simulation corresponds to a week in the life of the agent. Therefore the maximum age is roughly 96.

- <u>Expected Time of Death:</u>

Type: Integer
Range: Set with a Gaussian distribution, mean = 3800, variance = 1000.
Comments: The reason this is stated to be the *expected* time of death, is that an agent cannot die if they still have children in the house. This relieves the problem of catering for orphans.

- <u>Integration:</u>

Type: Float
Range: Between -1 and 1.
Comments: This represents the emotional maturity/health of an individual. The two extremes of this parameter lead to an integrated agent, and a traumatised agent. The former would be well integrated into society, having no trouble with their emotions, while the latter would be troubled and often unhappy, unable to cope with the past or present. It is equivalent to the sub-conscious.

- <u>Awareness:</u>

Type: Float
Range: Between -1 and 1.
Comments: This parameter represents how aware the agent is about themselves and their environment. An agent with a high level of awareness will understand his fellows, be well educated and have the ability to teach what they know. The other end of the scale is Indoctrination, which correspondingly means the agent will not understand their own emotions, and will easily follows the will of others.

- <u>Ego:</u>

Type: Float
Range: Between 0 and 1.
Comments: This represents the agent's level of self-esteem. An agent with zero self-esteem will be very critical of what others think of them, self-conscious, and unwilling to expose their feelings to other agents for fear of rejection. They will be introverted, and interactions with other agents will be strained. An agent with a high level of egoism will be self-confident and extroverted.

- <u>Strength:</u>

Type: Float
Range: Between 0 and 1.
Comments: This parameter determines the winner when two agents interact in a fight. This value is partly hereditary, based on a distribution with the normal set to the average of the agent's parents' strengths. However, strength can be increased by an agent when its cerebral ideal is greater than its strength (i.e. it has the desire to get stronger). This impulse occurs when the agent receives numerous teachings from a parent with a high cerebral ideal.

❖ Aggressiveness:
Type: Float
Range: Between 0 and 1.
Comments: This value determines how aggressive an agent is, affecting the way they fight and ridicule other agents. An agent who was beaten as a child is likely to be highly aggressive.

❖ Authoritiveness:
Type: Float
Range: Between 0 and 1.
Comments: An agent who received a high number of 'teachings' as a child will have a high level of authoritiveness (think of a mother instructing her children in every aspect of their lives). They will, in turn, repeat this pattern with their own children, imposing many teachings.

❖ Cerebral Ideal:
Type: Float
Range: Between 0 and 1.
Comments: This corresponds to an agent's desired level of sporting ability. This desire is imparted from the agent's parents, who through the 'Teach' interaction, try to instill their own values in their child. It is important to note that the agent's strength is not necessarily equal to the ideal – the ideal is a standard they wish to attain. It is however a driving force to reach those levels.

❖ Somatic Ideal:
Type: Float
Range: Between 0 and 1.
Comments: This measures an agent's desired level of education. This is imparted from the agent's parents in exactly the same manner as the cerebral ideal. This can affect an agent's performance at school and in the office.

❖ Narcissistic Supply:
Type: Float
Range: Between 0 and 1.
Comments: This is a parameter which only holds significance to the narcissistic agent. As described in Section 2.2, these agents will have a great need to receive attention from the outside world, and the amount they receive is indicated by this parameter. It is reset back to 0 at the end of every tick, so that during the course of each new tick, they attempt to reach their supply limit. A non-narcissistic person will have a limit of 0, so that they have no desire to get supply, whereas a pathological narcissist will have a limit of 1, so that all they desire during the course of a tick is to extract supply by any means possible. If this agent has not extracted a sufficient level of supply towards the end of a tick, it may opt for measures such as lying and fighting to receive it. A level of narcissist between the two aforementioned extremes will require a level of supply somewhere between 0 and 1 – this level is determined by a variety of factors, explained in the section 'Narcissism and the Model'.

3.4.2 Agent Parameter Initialisation:

At the beginning of the simulation, it should be assumed that the population has been operating under normal conditions for some time; and therefore it is necessary to initialise agents with estimates that represents the diverse nature of the entire populace.

This problem is easily solved with a distribution, which can spread the agents' parameters around a given mean. We can assume that in the real-world, a person's level of integration, ego and awareness is subject to a great number of factors; which means that a Gaussian (or Normal) distribution $N(\mu,\sigma)$ would be most fitting here to represent this. Without this function available to me, I created my own Gaussian generator, which works in a slightly unorthodox way, but produced good results.

The problem with the Gaussian distribution is that it produces values within the range $[\infty,-\infty]$, whereas our parameters require values between [-1, 1]. Therefore, some measure needs to be taken to adjust the values. I have discussed some methods below, and their counterparts are displayed in Figure 2.5.

(a) Using the original distribution leads to invalid results, so this is not usable.

(b) By using a form of Monte Carlo Simulation, I can simply discard invalid results in the following manner:

```
stop = false;
while (!stop) {
        float x = getGauss(0,1);
        if (x≥-1 && x≤1) {
                return x;
        }
}
```

However, this suffers from the drawback that more agents will take values at the extremes (see Figure 2.5(b)), which is undesirable if trying to take a valid snapshot of society.

(c) Another method is to *truncate* any invalid value back to the closest extreme (e.g. 1.54 would be truncated to value 1). However, this too means that we would get many more agents at the extremes than you would find in a true normal distribution. The effect of truncation can be seen in Figure 2.5(c).

(d) By *rescaling,* we could divide any valid or invalid result by 2, since this would place a high percentage of the distribution within the valid region. However, there would still be the occasional invalid result, which would introduce errors into the system (see Figure 2.5(d)).

I decided to use a combination of (b) and (d), since by rescaling, I could keep the shape of the distribution, and through the Monte Carlo simulation, my model could ignore the few invalid values I would receive.

I have used this method to initialise the model for the integration and awareness parameters amongst others. Ego has been set with a slightly modified version of this distribution, to allow values between 0 and 1 only. There were, however, some parameters which would did not suit a normal distribution; for example, the *age* of agents. By using a normal distribution, I would end up with the majority of agents being roughly middle aged. I therefore used a uniform random number generator to set values such as this one.

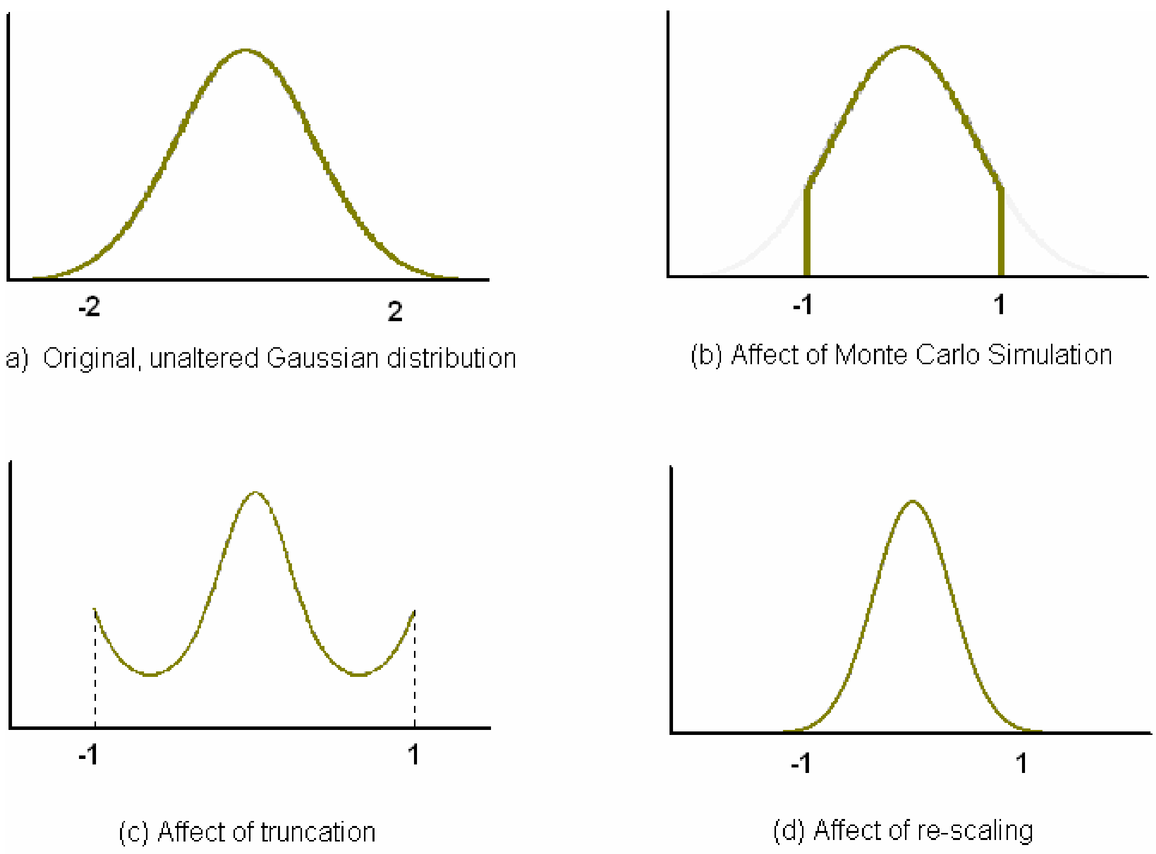


Figure 2.5. *Gaussian distributions and methods of getting valid results.*

3.4.3 Agent Lifecycle:

Agents go through many different stages in their lives; where *age* or *circumstances* dictate their regular activities. In this section, I shall explain these routines.

When an agent is born, it is considered a baby, and it has a very limited range of actions. Basically, it requests attention, and the mother and father can oblige, or ignore the request. This is fundamental in the creation of narcissism, since love and attention during the first 3 years of your life are imperative. In the course of one iteration, the agent:

- Interacts twice with its mother.
- Interacts once with its father.
- Optionally interacts once with either its mother or father.
- Increases age.

At the age of 155 (approximately 3 years old), the agent has completed the first character-creating epoch of its life, and the limits of their integration and ego parameters are set according to the amount of love and attention they received during these crucial years (see section 'Narcissism and the Model' for more details). Now, the agent has more interactions with its siblings, but all its activities remain within the household.

- Interacts twice with mother
- Interacts once with father
- Interacts three times with random members of the household
- Receives a teaching from father
- Receives a teaching from mother
- Increases age

At the age of 260 (approximately 5 years old), the agent goes to school for the first time. During each iteration, the agent will:

- Interact twice with mother
- Interact once with father
- Interacts three times with random members of the household
- Interact once within the direct neighbourhood.
- Interact twice with agents at school
- Receives a teaching from father
- Receives a teaching from mother
- Increases age.

At the age of 625 (approx 12 years old), the agent starts desiring more freedom.

- Interact five times with random members of the household
- Interact with two acquaintances in the neighbourhood.
- Interact with best friend in neighbourhood.
- Interact twice with random agents at school.

- Receives a teaching from father
- Receives a teaching from mother
- Increases age.

At the age of 935 (approx 18 years old) our agent becomes an adult. They are now able to move out of their parents' house, go to work, find a mate, and have children. At each iteration, the agent will:

- Interact with five members of the household.
- Interact with two acquaintances in the neighbourhood.
- Interact with best friend.
- Interact twice with random agents at the office.
- If not already moved out of parent's house, there is a 2% chance that the agent *will* during this iteration (providing there is an empty house free).
- Have a 0.5% chance of getting married (as long as one of the two agents has their own house).
- Increase age.

Once the agent is married, their routine changes yet again:

- Interact three times with partner.
- If agent has children, interact twice with each of them.
- Probability of having a child (see 'A Closer Look at Agent Epochs').
- Interact twice with members of the office.
- Interact once with best friend.
- Increase age or die.

3.5 A Closer Look at Agent Epochs:

3.5.1 Birth:

A married female agent has the ability to give birth to a new agent, but there are a few constraints: There have to be less than three children currently inhabiting her house (for reasons of capacity). Also, she must have had less than five children in her lifetime (even if they have already moved away), and the same must be true of her partner. In any given tick, the probability of a child being born to this agent is governed as follows:

$$P(\text{Give\_Birth}) = \sigma\left[1 - \frac{2}{5}\left(\frac{\text{numChildrenInHouse}}{\text{maxChildCapacity}}\right)\right]$$

$$\text{where, } \sigma \begin{cases} 0, & \text{if } ((\text{agent.totalChildren} \,\|\, \text{partner.totalChildren}) \geq 5) \\ 1, & \text{otherwise} \end{cases}$$

As you can see, each time an agent has a child, it becomes less likely that it'll have another. By the laws of probability, a couple will have their first child within 2.5 years of eloping, on average.

This is essentially the first stage of an agent's lifecycle: **birth**. If an agent is a 'natural' inhabitant of the system (i.e. not being created with the methods described in the section 'Agent Parameter Initialisation'), it will be born to household which contains a mother agent and a father agent. It's awareness, ego, and integration parameters will all be set to zero – in this sense, the agent has a clean slate. The remainder of its behaviour-describing parameters are set randomly to either one or the other of the parents' values, except for strength, which is taken as the average of the parents' strengths. All of these values are then mutated to a certain degree, so that no clone-like behaviour occurs.

3.5.2 Moving:

As mentioned above, any agent over the age of 935 is old enough to leave their parent's household, and move into their own. This is a very significant change, because their daily interactions will no longer be overwhelmed by the family; rather a new set of contacts will emerge. This is not to say that communication with the family will cease; rather that it will decrease.

The agent who has decided to move will search for an empty household within a Moore Neighbourhood of radius three. It will carry out its search in the order shown in Figure 2.6, looking for empty houses close to the parents to begin with. If no free houses can be found within the neighbourhood, it will abandon its search and try again in the future (each tick provides a 2% chance of starting a fresh attempt).

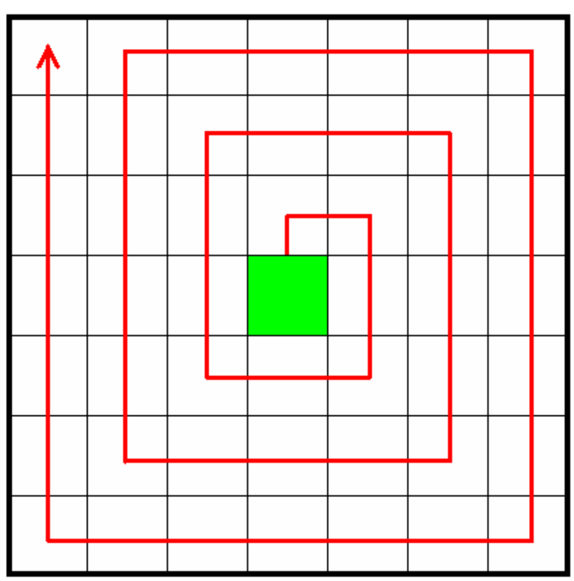


Figure 2.6. *Agent's order of search for a new household.*

3.5.3 Marriage:

If an agent owns a house, they have the ability to propose to another agent. They do this by looking through their contact lists (see section 'Relationships and Contact Lists') for eligible candidates. By this, I mean the agent has to be an adult (i.e. over 935 ticks in age), have no partner (adultery is not permitted in this model), and have no children currently living in their house. Both male and female agents are able to propose with equal likelihood; i.e. a probability of 0.5% at each tick. Once the agent has collected a list of their eligible contacts, they must decide which to choose as a (hopefully) permanent partner.

This is done via a scoring system for each contact, as per the equation below:

$$P(\text{Propose\_to\_Agent}) = \text{nLevel}\left(\frac{\text{awareness}+1}{2}\right) + (1 - \text{nLevel})\left[\frac{1000 - |(\text{age} - \text{partner.age})|}{5000} + \frac{4\,(\text{relationship}+1)^2}{20}\right]$$

This scoring system gives points to each agent between 0 and 1, with 1 being the highest probability of proposal. The agent loops through all their eligible contacts, and the agent with the highest score is the one who will receive the proposal. I will now give a quick explanation of this equation.

I will first consider the right hand side of the equation, enclosed in the square brackets. The average agent will rate a potential partner based on their age, and their relationship. If the two agents have very similar ages, this increases the agent's score – but over 1000 ticks difference results in negative points being awarded. However, this has been weighted as only one fifth of the decision (since a person is unlikely to choose a mate based on their age alone).

The other 4/5 is dedicated to their current relationship. The relationship parameter takes values between -1 and 1, which has been appropriately updated so that the exponential takes account of the parameter's sign. The reason for the square is so that agents who have a very high-degree of affection for each other are far more likely to get married than agents with a mediocre relationship. Marriages of mediocrity are rarely embarked upon. *A truly love-struck couple will have a much higher chance of eloping.*

Now, to take into account the rest of the equation, we have to consider the narcissistic agent. The level of narcissism is shown here as 'nLevel', and its derivation is explained in the section 'Narcissism and the Model'. Basically, a pathological narcissist (i.e. with the highest level of narcissism), will be consumed by their need for *supply* (as discussed in previous sections). Supply is most easily extracted from agents with a low level of awareness, since it is harder for them to see the narcissist's true, ugly self and are less likely to discover their duplicity and lies. Also, it allows the agent a feeling of self-satisfied superiority to have someone with a lower level of intelligence around.

This is for the extreme cases of pathological narcissism, where an agent has no concern for the feelings or well-being of others; and so makes the decision based only on how the marriage will boost their weak ego. Most agents are either not at all narcissist, and so do not take this into account, or they are somewhere in between, and therefore weight the extremes of selfishness and love based on their level of narcissism.

3.5.4 Death:

An agent dies based on an 'Expected Age of Death' parameter, which gets its value from a normal distribution at birth. It may seem somewhat illogical to determine the date of death at the early stage of birth. However, probing a distribution for every single agent at every iteration, to determine if they'll die during this tick, makes little sense if one considers optimising the simulation's speed. Rather, it is better that a single probe of the distribution be made for each agent.

If an agent has young children in the house, it cannot die unless it has a partner who can look after them. Otherwise, the agent can be removed from the household, from all relationships and from the model. In the situation where the agent has *adult* children still living in the house, it can die and leave a *will*, whereby the eldest child inherits the house. In this case, that child becomes the owner of the house, and gets the freedoms that this entails.

3.5.5 Contact Lists and Relationships:

The behaviours of an agent are dependent on two things only: the mental parameters of the agents involved in an interaction, and their relationship. This makes sense, considering that even the most emotionally healthy person will react differently towards friends than towards enemies.

A relationship stores the two agents involved, and their level of affection for eachother (see Figure 2.7). This is held as a parameter which can vary between -1 and 1. It is symmetric around 0: with a level of 1 signifying that the agents are very good friends, a level of -1 signifying a mutual hatred, and a level of 0 indicating neutral feelings. When an agent meets a new contact, their relationship will naturally be set to 0. It is important to note that a relationship is *commutative*, meaning that A's relationship to B will be equal to B's relationship to A.

Another important parameter is the *familial bonus*. This pertains to the special links between family members, and how this affects interactions. For example, having a talk with a parent is likely to be more significant than a talk with an acquaintance, just as a fight with a friend is far less traumatising than a fight with a family member. This bonus determines how far an agent takes to heart what another agent says or does, affecting the update of their own parameters. A parent has a bonus of 0.9, siblings and children have a bonus of 0.4, and a partner has a bonus of 0.75. Any other agent has a bonus set to 0. These stay constant through time, though the relationship parameter can fluctuate greatly.

There are a number of other parameters stored within a relationship, and these hold a compact history of past interactions between the two agents. This history is critical to narcissistic agents, which I shall be explaining further in section 'Narcissism and the Model'.

Each agent stores two contact lists; one for family members (whether currently residing in their household or not), and one for non-family members (see Figure 2.8). Initially, these two lists were combined, but I found that distinguishing them increased the speed of the simulation. It allows for ease of retrieval, so that direct family members can be found instantly, rather than through a search of all an agent's contacts. Another measure for space-optimisation was the cleanup of contact-lists. Because agents move in and out of houses all the time, there can be quite a build up in the contact lists, and they can grow quite large. Agents moving away might also leave details in other agents' lists who they're unlikely ever to contact again, which adds redundancy to searches. Therefore, each relationship is given a timestamp for the last interaction between the agents. Every fifty ticks, the contact lists (for non-family agents) are pruned, removing agents who have not interacted since the last clean up.

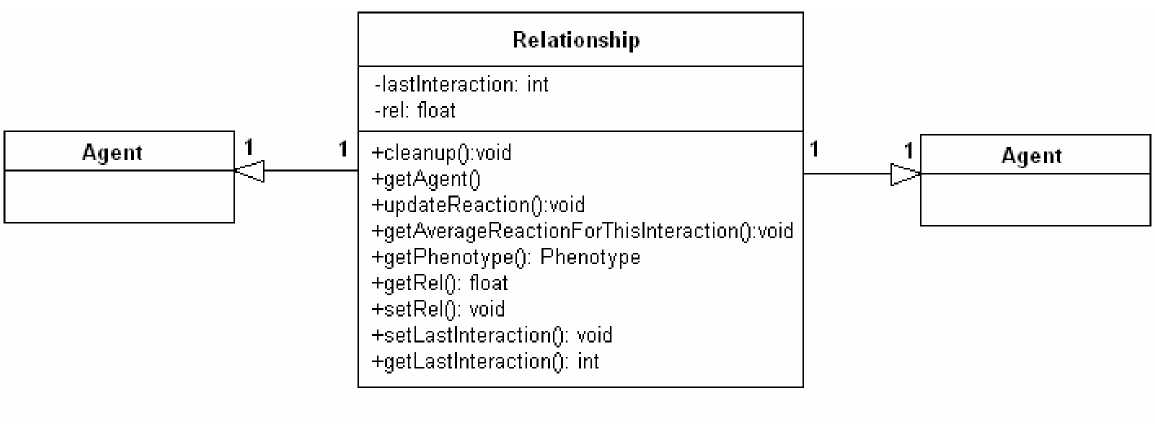


Figure 2.7. *UML Diagram for Relationship*

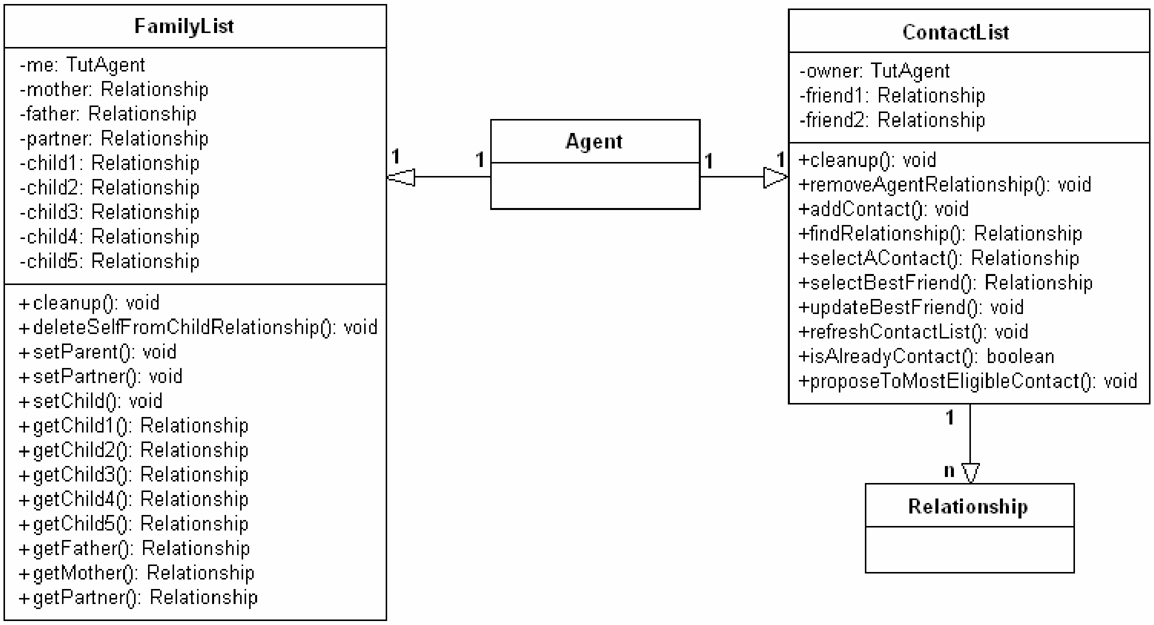


Figure 2.8. *UML Diagram displaying both agent contact lists.*

3.6 Interactions:

There are six possible interactions in the model.

- Talk
- Ridicule
- Compliment
- Lie
- Teach
- Request Attention

The latter interaction can only be made by babies, who have no other means of communication. The results of performing any of these actions affect the relationships of the two agents involved, and their mental parameters; though the change can be vastly different depending on a number of factors. In any interaction there will be an *active* agent and a *passive* one: the active agent initiates the interaction, and the passive one is forced to take heed. Therefore, the life-cycles shown in the previous section do not bear all of the interactions any agent may experience; only the ones which they initiate themselves.

First of all, I will give an overview of the entire process of an interaction:

- Selection of a partner
- Selection of an Interaction
- Get agent's reaction to interaction.
- Update Parameters.

3.6.1 Selection of a Partner:

This is the simplest step, since the choice of agent-group to interact with is pre-defined by the life-cycle. Therefore, if an agent has to interact with a parent, that agent's details can be found in their FamilyList. The same is true of explicit external contacts like 'Best Friend' – since at the end of each interaction, an agent compares their relationship to their passive friend, to determine if is better than that with their current best friend; therefore, this agent's details can be found instantly.

It becomes a little harder when only a group of agents has been defined for interaction: e.g. someone at the office/school, someone in your contact list, someone new in the neighbourhood… In these cases, the agent has to perform a random uniform search of either their contact list, or their list of work-mates. When searching for a random neighbour in their neighbourhood, a similar approach is taken with the resulting Moore Neighbourhood list; which consists of all agents (within their age range) from the eight surrounding houses.

3.6.2 Selection of an Interaction:

This represents the entire decision making process of the agent, and is thus a very important stage of the interaction. Every agent must understand the current circumstances they find themselves in, in order to make an appropriate decision on the interaction to make. These circumstances consist of the two agents' state of being (i.e. their internal parameters) and their past relationship. The specific factors taken into account are the agent's level of Integration, Ego, Awareness, the difference in awareness between the two agents, their relationship, their current need for narcissistic supply, and their level of authoritiveness and aggression. This can be expressed as a vector, 'C':

$$\vec{C} = \begin{bmatrix} \textit{integration} \\ \textit{ego} \\ \textit{awareness} \\ |\textit{partner.awareness} - \textit{awareness}| \\ \textit{relationship} \\ \textit{narcissistic defecit} \\ \textit{authoritiveness} \\ \textit{aggressiveness} \end{bmatrix}$$

This vector is normalised for ease and speed of calculations. However, this gets us no further towards finding a suitable interaction to take; it merely gives us an overview of the agent's emotions towards their partner (NB: herein, partner refers to the *passive* agent).

A decision is made by a formulation for the *ideal situation* for every type of interaction. These can be represented as normalised vectors, in exactly the same manner as above:

$$\overrightarrow{\mathbf{I}(talk)} = \begin{bmatrix} 0.308 \\ 0.759 \\ 0.410 \\ 0.256 \\ 0.308 \\ 0.0 \\ 0.0 \\ 0.0 \end{bmatrix} \quad \overrightarrow{\mathbf{I}(compliment)} = \begin{bmatrix} 0.685 \\ 0.493 \\ 0.412 \\ 0.273 \\ 0.209 \\ 0.0 \\ 0.0 \\ 0.0 \end{bmatrix} \quad \overrightarrow{\mathbf{I}(fight)} = \begin{bmatrix} -0.305 \\ 0.208 \\ -0.232 \\ 0.244 \\ -0.366 \\ 0.458 \\ 0.183 \\ 0.611 \end{bmatrix}$$

$$\overrightarrow{\mathbf{I}(lie)} = \begin{bmatrix} -0.384 \\ 0.160 \\ 0.352 \\ 0.543 \\ 0.0 \\ 0.639 \\ 0.0 \\ 0.0 \end{bmatrix} \quad \overrightarrow{\mathbf{I}(ridicule)} = \begin{bmatrix} -0.351 \\ 0.422 \\ -0.320 \\ 0.452 \\ -0.428 \\ 0.357 \\ 0.0 \\ 0.285 \end{bmatrix} \quad \overrightarrow{\mathbf{I}(teach)} = \begin{bmatrix} 0.0 \\ 0.288 \\ 0.447 \\ 0.288 \\ 0.180 \\ 0.288 \\ 0.720 \\ 0.0 \end{bmatrix}$$

These values are by no means random (the level of precision is an effect of normalisation). Each represents the most ideal circumstances in which to undertake that interaction. Therefore, looking at the *fight* vector, we see that an aggressive agent with a low level of integration, ego and awareness needing a high level of supply, will attempt to fight an agent with a similar level of awareness who he has a bad relationship with.

Note that the values shown here are not directly taken from the relevant parameters – since a level of truncation occurs during normalisation. These vectors simply give an ideal *direction* for the interaction. For instance, the ideal integration level for a fight integration is not actually -0.305, it is -0.5. A code snippet is shown below:

```
fightVector[0] = -0.5f;
fightVector[1] = 0.34f;
fightVector[2] = -0.38f;
fightVector[3] = 0.4f;
```

```
fightVector[4] = -0.6f;
fightVector[5] = 0.75f;
fightVector[6] = 0.3f;
fightVector[7] = 1f;

sum = 0;
for (int t=0; t<numFactors; t++) {
     sum += Math.pow(fightVector[t],2);
}
sum = (float)Math.sqrt((double)sum);
for (int t=0; t<numFactors; t++) {
     fightVector[t] = fightVector[t]/sum;
}
```

This code takes the form of the equation shown below for normalisation:

$$parameter_j = \frac{parameter_j}{\sqrt{\sum_{i=0}^{7} \left(parameter_i^{\,2}\right)}} \quad , \text{where } j = 1 \text{ to } 7$$

I have normalised each vector so that it can be cast as a projection onto the current circumstances. In this way we can compare the current situation to the ideal situation for any interaction, and see which one bears closest resemblance:

$$C \cdot I \;=\; |C||I|\cos(C,I) \;=\; \cos(C,I)$$

Through normalisation, we can eliminate the |C| and |I| factors of a scalar product, and instead determine a *score* for the interaction, based solely on the angle between the two directions. This can be shown geometrically in Figure 2.8. Each interaction vector corresponds to a direction in a given state-space (shown in the figure in 2 dimensions for simplicity, though in reality it corresponds to 8 dimensions). By taking the scalar product between the current situation vector, and the interaction vectors, we get a value between -1 and 1, where a higher number signifies a smaller angle between vectors.

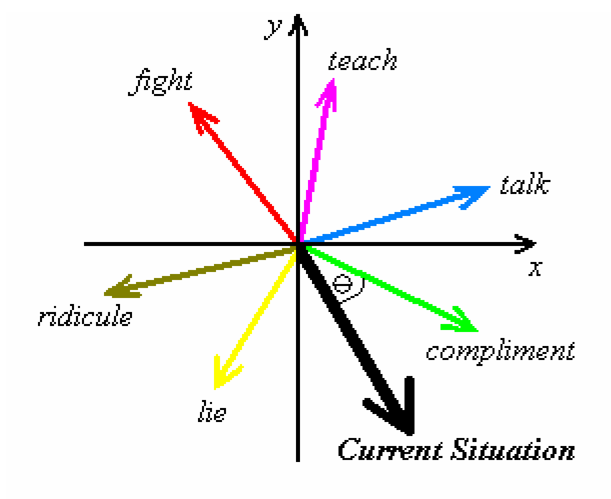


Figure 2.8. *Geometric view of the decision function.*

-1 is returned from the scalar product if the vectors point in *opposite* directions, and 1 is returned if the vectors are *equal*. We can therefore use this as a direct scoring system, to determine which interaction is most ideally suited to the current situation:

$$\text{Score}(\textit{interaction}) = \vec{C} \bullet \overrightarrow{\mathbf{I}(\textit{interaction})}$$

The interaction that bears the highest score is the interaction selected for execution with the other agent. (NB: This isn't actually the entire scoring system. There are other factors involved which will be described in the section 'Narcissism and the Model').

3.6.3 Update Function:

3.6.3.1 Retrieving Agent Reactions:

The success or failure of any interaction is decided by the passive agent's reaction to the interaction. This is valued between -1 and 1, with the former equalling a very bad reaction, and the latter indicating a very good reaction. It is easy to see that the 'Fight' interaction will always yield negative results, as will the Ridicule action; whereas Talking and Complimenting are pro-social interactions, and will hence provide a positive reaction. 'Teaching' is a neutral action, so the reaction is always taken as so (but when considering narcissism, the quantity of teachings is very important, because this can indicate a pushy, over-bearing parent, which is a significant factor in the creation of narcissism). Lying can produce both positive and negative results, since it is non-deterministic in part. If the passive agent sees through the lie, then it will yield a negative result, whereas if they are duped, they will feel wonder towards the grandeur of the active agent (who has apparently done a fantastic thing, as the lie suggests), and so the reaction will be positive.

The magnitude of these reactions, whether positive or negative, are determined by factors such as the agents' relationship, and their mental parameters. (Consider that a physical fight with a mortal enemy will be much less shocking than with someone you are very close to).

- **Talk/Compliment/Ridicule Actions:**

These are very similar interactions, in that they entail a conversation with differing levels of spite or friendship behind them. The reaction is therefore calculated in a similar manner.

It is initially scored between 0 and 0.5 (I shall term this the *reaction score*). This score is then weakened/strengthened depending on the type of interaction. Ridiculing can only result in reactions between -0.5 and 0 (because no agent will ever enjoy being ridiculed). Therefore this is calculated as -0.5 + reaction score. Talk and Compliment work similarly, with ‘Talk’ taking values between 0 and 0.5 (i.e. 0 + reaction score), and ‘Compliment’ taking reactions between 0.5 and 1 (i.e. 0.5 + reaction score). The reaction score is calculated as follows:

Reaction score = ((egoFactor*(1 - (2 * difference in ego)
+ awarenessFactor * (1 – difference in awareness)
+ relationshipFactor*relationshipReaction) + 1) / 4;

The first two terms yield a negative reaction if the two agents’ egos are completely opposite, and their levels of awareness are completely opposite too. This is then scaled to fit values between 0 and 0.5. This makes sense, since an agent with a low level of awareness or education will not grasp the content of an agent with higher awareness - and similarly the agent of higher awareness will not find the conversation mentally stimulating enough. Also, if the agents have different ego levels, they are not suitably matched for conversation, since an agent with low self-esteem will not feel so comfortable with an agent who is self-confident and overpowering.

The final term determines a reaction (between -1 and 1), based on their current relationship, and this value is calculated from the graphs shown in Figure 2.9. ‘Talking’ gives the best reaction during the early stages of a relationship, when the agents have neutral feelings for eachother. This can be seen in reality, because conversations with an enemy aren’t usually so well received, whereas conversations with old friends are almost a form of keeping the status-quo in a relationship.

Ridiculing gives the most negative reaction if it comes from someone close to you, i.e. with whom you have a good relationship; whereas if it came from someone you dislike, it wouldn’t have as much of an effect (since by that point, you’d either be used to their critique, or you wouldn’t have any regard for their opinion).

Complimenting is an ego-boosting, universally enjoyed interaction. (In reality, there is actually a small subset of people who dislike compliments; but I have abstracted them away in this model). A positive reaction is given no matter what the state of the relationship; though the effect is diminished somewhat with people you are very close to (since, as with the talking interaction, at a certain point the interaction bears closer resemblance to keeping the status quo).

We therefore have an Ego, an Awareness, and a Relationship factor to these interactions. However, it would be non-sensical to give them equal weighting in resolving the overall magnitude of reaction. Consequently, I have weighted each term with the following values:

egoFactor = 2/10;
awarenessFactor = 5/10;
relationshipFactor = 2/10;

These are editable model parameters, so that the user can witness the effect of altering them.

```
 /*
 *GRAPH OF REACTION TO TALKING, BASED ON RELATIONSHIP
 *
R  1 |      /|\
E    |     / | \
A    |    /  |  \
C    |   /   |   \
T    |  /    |    \
I    | /     |     \
O  0 |/______|______\__
N    -1      0      +1
        RELATIONSHIP

 *
 *GRAPH OF REACTION TO RIDICULING, BASED ON RELATIONSHIP
 *
R  0 |\
E    | \
A    |   \
C    |     \
T    |       \
I    |         \
O -1 |____________\__
N    -1     0     +1
       RELATIONSHIP

 *
 *GRAPH OF REACTION TO COMPLIMENTING, BASED ON RELATIONSHIP
 *
R  1 |___________
E    |           |\
A    |           | \
C    |           |  \
T    |           |   \
I    |           |    \
O  0 |___________|_____\_
N    -1        0.4     +1
        RELATIONSHIP


 *GRAPH OF REACTION TO FIGHTING, BASED ON RELATIONSHIP (QUADRATIC)
 *
R  0 |\
E    |\
A    | \
C    | \
T    |   \
I    |      \ _ _ _ _ _
O -1 |__________________
N    -1        0       +1
        RELATIONSHIP
```

Figure 2.9. *Graphs of reaction based on relationship*

- **The Fight Reaction:**

A fight will yield the same reaction from an agent whether they win or lose – it is the *idea* that the person wants to fight them that they are reacting to. (On the other hand, the update of mental parameters in the update function *is* altered depending on the fight's outcome).

Reaction score = narcissistFactor*(1-(active. NarcissismLevel*2))
- awarenessFactor*(passive. AwarenessLevel)
+ relationshipFactor*relationshipReaction)
+ agroParameter*active.aggressiveness);

This takes into account the aggressivity of the attack, the level of narcissism of the attacker (who will fight with less conscience), and the awareness of the passive agent. The latter has been taken into account because the passive agent will suffer different states of shock depending on how aware they are. An agent with a high level of awareness understands the world, and why things like such attacks happen. An agent with a low level of awareness cannot understand the attack, could not have foreseen it, and therefore react with more shock and indignance. Finally, the relationship reaction is included again, which this time takes its result from the following function:

$$reaction = ((relationship / 2) - 0.5)^2 - 1$$

The quadratic element reflects the high level of emotional turmoil the attack instils from anyone who you considered a friend. With someone you dislike, the reaction is respectively downgraded, because the attack doesn't represent damage to a healthy relationship.

The components of this equation are weighted (as before), and are defaulted to the following (editable) values.

relationshipFactor = 1/2;
agroFactor = 1/4
narcissistFactor = 1/8;
awarenessFactor = 1/8;

- **Lie Reaction:**

This interaction models deceit, which is why it is fitting that the reaction be non-deterministic. Any agent has the possibility of believing the lie, or seeing through it; and each response leads to a completely different reaction. Here lies the stochastic element of this encounter. Even the most aware and intuitive friend has the ability to be fooled by a lie, and even the most gulliable fool has the ability to see the truth. But the probability of discovery is altered depending on which you are:

```
If  ( randvar(0,1) <   awFactor*((passive.Awareness+1)/2) + pastFactor*lieProb ) {
        //DISCOVER THE LIE
} Else {
        //BELIEVE THE LIE
}
```

The clause at the top displays two factors which determine whether a lie is discovered: an awareness factor and a past history factor. The former simply states that the lower the agent's awareness, the lower the probability of seeing through the lie. The latter determines a probability of discovery based on the two agents' history of past interactions (which is stored in the Relationship class).

If the passive agent has discovered lies from the active agent in the past, this will decrease the probability of believing the agent this time. Notice how the large jump between '0' and '1' lies could represent a bond of trust being broken.

Number of Past Lies Discovered	Probability of Discovering New Lie
0	0.0
1	0.4
>=2	0.55
>=5	0.85
>=8	0.95
>=10	1.0

These two factors of *awareness* and prior-knowledge of an agent's *dishonesty* are weighted with:

awFactor = 0.5
pastFactor = 0.5

As with the other factors, they are fully editable. The reactions associated with the two possible responses are as follows:

```
If (lie_discovered) {
        Reaction score = ((-relationship-1)/2);
Else {
        Reaction score =  0.8 + randVar(- 0.2, 0.2);
}
```

If the passive agent is fooled by the lie, they feel an overwhelming amount of respect for the active agent, and thus give a highly affirmative reaction. This reaction is random, in the interval [0.6, 1.0], aiming to reflect varying levels of splendor in a lie.

A narcissist is most likely to lie when they are low on supply, for precisely the reason that it yields so much attention. However, they will usually attempt to deceive an agent who has a low awareness, so as not be discovered.

3.6.3.2 Hysteresis Cycles:

After an interaction, an agents mental parameters have to be updated to reflect the new information. In this way, an agent's state of mind evolves as time passes. The method I shall be invoking with which to ascertain the change, is the *hysteresis cycle*.

Hysteresis is a property of (usually physical) systems that react slowly to forces being applied to them, and they often do not return to their original state after the forces retract. The state of such a system depends on its immediate history. Consider a piece of putty, which assumes a new shape when squeezed, but does not return to its original form when your hand is removed.

This is an adept method of change when considering an agent's mental state. It takes into account the plasticity in the rate of emotion modification, and the limits of the parameters. An agent is able to approach extremes at a faster rate than they can leave them. Take a person who has been abused mentally or physically; how easy it was for the damage to occur, and how hard it is to repair. Or on the opposite end of the spectrum, consider the slow breakdown of a once perfect relationship. It is unlikely to take place over night (unless there has been a significant event, but these cycles can cater for that).

This rate of change can be seen in Figure 2.10. Each red line indicates a rate of change; and the greater the size of the angle between the red and blue lines at any point, the faster this rate is (this will be shown diagrammatically in the next figure). As extremes are reached, there is a steady slow down in increases/decreases of the parameter, which reflects nature. For instance, how much harder is it to increase a relationship from a level of 0.96 to 0.97, than it is from 0.25 to 0.26? Very few people have a relationship as strong as the former case, because it is exceptionally hard to obtain. Great effort, and a lot of time is required (hence the deceleration in the rate of change). Conversely, the amendment in the latter case is comparatively insignificant.

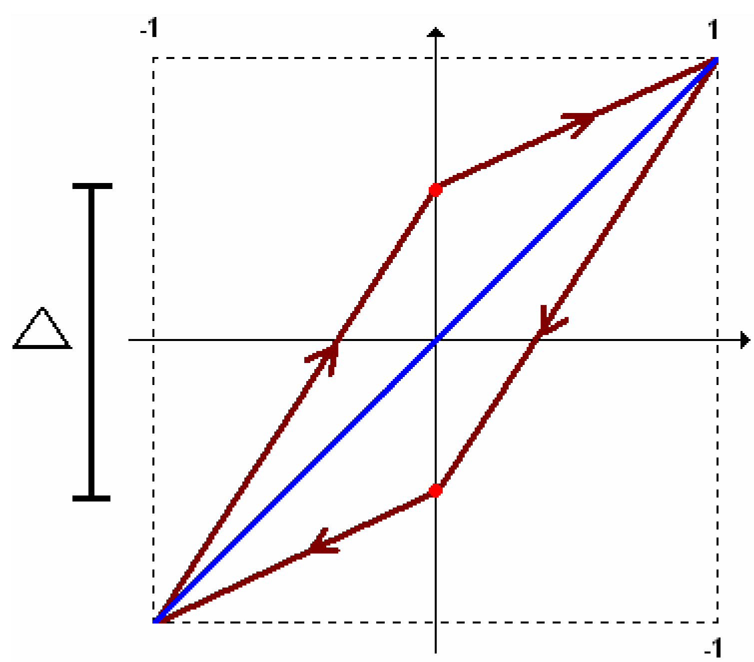


Figure 2.10. *Hysteresis Cycles*

I chose this method, because it keeps a complete history of all the parameter's former values, with no space considerations at all. It uses this to realise the real power behind an indoctrinated individual for instance, adding an almost qualitative dimension to the parameter.

This method has the added benefit of not allowing extreme values to be exceeded, by having an infinite slow-down of the rate at the extremes. This could potentially create fixed points, but I have eliminated this possibility by forcing the rate to stay above a certain low value (~0.003) so that it does not become impossible to escape.

Figure 2.11 shows the change in a parameter's value. This value is determined by your current position on the x-axis. If you wanted to increase your parameter, you would take your x-axis position on the blue line, draw a vertical line upwards to the red graph, and then a horizontal line back to the blue line. The x-axis value of your new position is the new value of your parameter.

When you wish to decrease the parameter, you do exactly the same, except you draw your vertical line *downwards*.

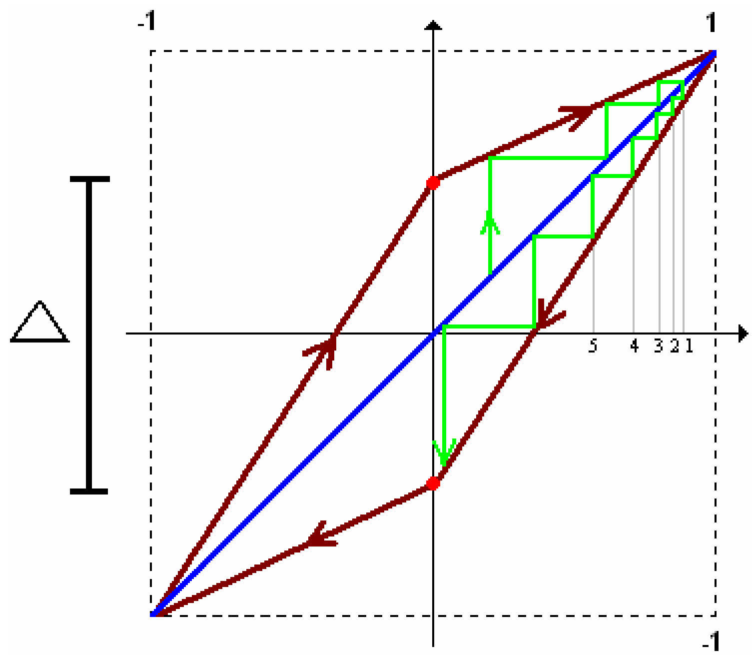


Figure 2.11. *Parameter change in a hysteresis cycle. Three steps up, and six steps back down.*

As you can see from the diagram, the extreme point of 1 is approached within 3 steps, but it takes 6 steps backwards to exceed your initial position. The grey lines in the figure show this decrease and subsequent increase of rate. The Δ parameter shown in the figure is the *magnitude of modification*. This determines the second derivative of this function – i.e. the *rate* of the rate of change. With a low magnitude, the parameter converges very slowly, and with a high magnitude, it converges very quickly (fluctuating rapidly, displaying much more erratic behaviour). This can be related to an individual who is highly insensitive to his surroundings, and respectively to a very self-conscious person.

Each agent has a separate hysteresis cycle for each of their parameters. These cycles have their own magnitude values, which can be set by the user. I have gone one step further, and also allowed the *dynamic modification of ranges.* This allows run-time adjustment of the extremes used in the cycle, so rather than keep them as -1 and 1, as in the figure above, they can be changed to anything; 0.4 and 0.8 for example. This involves re-calculating all graph equations (and can be viewed in the appendix code).

This dynamic adjustment is a very important feature, because it allows me to flexibly limit the emotions of agents. The reason this is so useful is because agents have periods of their lives which are of greater significance to the development of their character than other periods (early childhood for instance). This allows me to reflect that.

3.6.3.3 Applying the Update:

Now that we have calculated an agent reaction to the interaction, it is time to use it to update both agents' parameters. In this section, a subscript '1' always refers to the active agent, and a subscript '2' refers to the passive agent. Therefore $integration_1$ is indicative of the active agent's integration level. Throughout this section, reaction takes the new form of: Reaction = round(Reaction * 6), where 'round' indicates the process of standard mathematical rounding to the nearest integer. The term 'Reaction' will also be shorthanded to 'R'.

- **Talk Interaction:**

This is a pro-social interaction, which will be the most common throughout the system. It is a means of passing on information, causally enjoying one-another's company, and ensuring a healthy and happy self. However, one should note that active ignoring can occur, which by contrast is very damaging, especially to a child. This is the result when a reaction is near zero – i.e. no reaction was made. On a long-term scale, this can be about as harmful to emotional health as flagrant abuse.
<u>Reaction = 0 to 3</u> - *this is the range of possible integer values which reaction can take.*

- Awareness_1 increases by R steps
- Awareness_2 increases by R steps
- Integration_2 increases by R steps
- Relationship increases by (R/2) steps

To deal with the case where active ignoring is occurring:

- If (R=0) Integration_1 decreases by one step
  Ego_1 decreases by one step
- Else Integration_1 increases by R steps

The awareness of both agents increase during this interaction, because talking is a process of learning and communication passing, as well as enjoyment. Integration also increases (unless ignoring occurs), because talking is a natural and emotionally fulfilling interaction (to take it to the extreme, consider the effect of counseling).

o Ridicule Interaction:

This is an anti-social interaction, and can have powerful effects on ego, destroying a relationship if repeatedly used. The active agent attempts to hurt their partner (i.e. passive agent) mentally, and this is modeled by a decrease in their Integration. However, the passive agent gets an increase in awareness, since the interaction fuels their knowledge of this less pleasant aspect of the environment. The perpetrator on the other hand loses awareness. Subconsciously, they would feel some turmoil at the effect of their behaviour, which would subsequently be shut down or ignored, so that they can continue with life. Finally, the passive agent will have a bruised ego from this interaction (since ridiculing is usually very personal), and the relationship between the agents will decrease. (NB: the phrase 'increase' and 'decrease' below is purely for clarity – do not assume double negatives).

<u>Reaction = -3 to 0.</u>

- $Integration_2$ decreases by R steps
- $Awareness_1$ decreases by (R/2) steps
- $Awareness_2$ increases by (-R) steps
- Ego_2 decreases by R steps
- Relationship decreases by R steps.

- (*Familial Bonus:* Relationship also decreases by (Bonus*R/2) steps)
- (*Familial Bonus*: Integration decreases by Bonus*R steps)
- (*Familial Bonus*: Ego decreases by Bonus*R steps)

o Compliment Interaction:

This is a very noble, selfless action, which doesn't affect the active agent's parameters. Their partner however receives an ego boost, and their integration increases. A narcissist is unlikely to ever offer this interaction, because it doesn't help their low self-esteem, but they will always want to receive a compliment.

<u>Reaction = 3 to 6.</u>

- Ego_2 increases by R steps
- $Integration_2$ increases by (R/2) steps
- Relationship increases by R steps
- (*Familial Bonus*: Ego also decreases by an extra (Bonus*R)/2 steps)

- **Fight Interaction:**

Every fight has a winner and a loser, determined by the strength of both agents and a probabilistic element. It is a highly anti-social behaviour, which has negative affects for all involved. A fight always traumatises both agents, owing to the dehumanising nature of the interaction. (The loser has a reduction of integration twice as high as the winner, though there is a bonus reduction if the initiator loses the fight). The passive agent will get an increase in awareness (for the same reasons as applied in Ridicule), and if the active agent wins, he will lose awareness (he started a fight and won - giving a false sense of power). No matter who initiated the fight, the loser will always get a decrease in ego, and the winner will always get an increase; since victory always gives a sense of self-worth.

<u>Reaction = -3 to -6.</u>

If the active agent wins the fight:

- $Integration_1$ decreases by (R/2) steps
- $Integration_2$ decreases by R steps
- $Awareness_2$ increases by (-R/2) steps
- $Awareness_1$ decreases by (R/2) steps
- Ego_1 increases by 1 step
- Ego_2 decreases by 1 step

If the active agent loses the fight:

- $Integration_1$ decreases by (R-1) steps
- $Integration_2$ decreases by (R/2) steps
- $Awareness_2$ increases by (-R/2) steps
- Ego_1 decreases by 1 step
- Ego_2 increases by 1 step

In either case, relationship is decreased by R steps.

- (*Familial Bonus:* Relationship also decreases by an extra Bonus*R steps)
- (*Familial Bonus*: Integration decreases by Bonus*R steps)
- (*Familial Bonus*: Ego decreases by (Bonus*R)/2 steps)

- **Lie Interaction:**

This is an ambiguous type of interaction, because although it is a morally negative thing, if it succeeds, it can increase the well-being of both agents involved. The person telling the lie will get an ego boost (the very reason for initiating the action), and the agents will enjoy an increase in their relationship. However, the deceitful agent will also get a reduction in awareness – because they have lied and got away with it – making them have a higher belief in the utility of lying.

If the lie is discovered, the active agent will sustain a decrease in their ego, and their awareness will increase (a reversal of the process described above). Unfortunately, the relationship between the two agents will suffer a huge reduction, because the active agent will want to distance themselves from their 'unmasker'.

If lie is discovered:

<u>Reaction = -6 to 0</u>

- Ego_1 decreases by R steps
- $Awareness_2$ increases by R steps
- Relationship decreases by (-2*R-1) steps

If lie is believed:

<u>Reaction = 0 to 6</u>

- Ego_1 increases by R steps
- $Awareness_1$ decreases by (–R) steps
- Relationship increases by (R/2) steps

3.7 Narcissism and the Model:

3.7.1 Introduction:

In my model, a narcissist is defined by the two parameters: *Ego* and *Integration.* It was my research of this complex and paradoxical subject that led me to include these parameters in the first place; because they are highly indicative of what constitutes a narcissist.

A narcissistic individual is defined as such, if they have a low self-esteem and have been traumatised. This is almost always defined during the early years of life, when a person is just forming their views of the world and their place within it.

Essentially, when first born, all children are narcissists, but not in the pathological sense: this is an important distinction. There are narcissists who just have an inflated sense of self, who believe they are the centre of the world, because they have always been led to believe so. Through pampering and scrupulous attention towards their needs, they think themselves superior, and take this attitude with everyone they meet throughout life. They are termed *classic* narcissists. This is essentially the outlook a baby has when brought into this world. All they know is themselves, everything they see and hear is an extension of themselves, and everything around them must therefore be a servant to the self. This is perfectly natural and healthy. Eventually, through frustration, they learn their own limits, and gradually recognise others in their world, growing the ability to empathise.

The classic narcissist is not, however, the subject of this model. They are common in any society, and do not display any particularly interesting features to model. The more 'dangerous' and emotionally damaged form of narcissist is the pathological narcissist, who is created in the exact opposite way as the classic narcissist. Whereas the latter is classified by their very high ego, the former is classified by their very low ego. This is interesting when you consider that they've been categorised under the same name (though the reason will become apparent).

As a baby, the most important thing for them is *attention*. I cannot emphasise this strongly enough. Because they think they are the centre of the world, any cry for attention (e.g. demanding sustenance) should be dealt with immediately. They are the master of their own worlds, and everything should happen as they need it to. When a parent shows the child love, they are validating the child's self-importance. Put in another way, they are sustaining the child's self-esteem.

However, when a child does not receive that previous love and attention, their view that they are the centre of the world is diminished. At such an early age, this does irreparable harm, because this is when you are forming your own view of yourself – a view which stays with you for the rest of your life. It is plain to see how damaging a loss of self-esteem at this early age is.

According to Freud, there are two types of love: *ego libido* and *object libido*. The former is libido directed inwards towards yourself, whereas the latter is libido directed towards another person.

A baby needs to receive a high amount of object libido from the mother, in order to sustain their levels of self-esteem, and their confidence that they are the centre of the world. A neglected child will not receive this regular intake of love, but would still need to 'top-up' their level of self-esteem. They will therefore be forced to *self-love*: i.e. ego libido.

This is where narcissism comes in. Not only will they be traumatised from neglect, but also they will have a very low sense of self-esteem. The view that the world is their's is destroyed, so they cocoon themselves within their own body, sustaining their own ego through self-love.

This is the definition of a pathological narcissist used in my model: A person who is emotionally unhealthy as a result of neglect or abuse, with a low level of self-esteem. Their self-worth is boosted by loving themselves, hence creating narcissism.

It is an incredibly paradoxical concept, because real ego is not fostered by the love of oneself – ego is formed from the love of someone else for you. The narcissist is essentially fooling themselves into believing that they are loved, by providing the love themselves; whereas in reality, they have a very low self-esteem.

At an older age, this manifests itself through *the splitting of the self*. This concept means that the person has two halves to their personality: The real self is the emotionally damaged person, who is self-critical, low in self-esteem and self-confidence and who hates themselves (no-one else has ever loved them, so why should they?) This is a subconscious level however, and the narcissist themselves do not acknowledge its existence. The false self is the front they present to the world, with a false level of self-esteem which has been created by their own, forced, self-love. It acts as a barrier between the cruel and ungiving world, and their wounded real-self. By not exposing their pain, or accepting its existence, the person is able to cope with day to day life.

To the pathological narcissist, nothing is more important than feeding their desperate desire for attention. Deprived so badly of attention at a young age, it becomes absolutely vital to them that they receive as much attention as possible, to soothe the bruised ego (though it is too late to permanently bolster the ego; their low level of self-esteem is fixed at an early age - it becomes inbred, a very part of their character). This is the primary function of the false self; to get this attention to soothe the crippled real-self. It becomes a permanent cycle of trying to get attention, for a cup which can never be filled.

This is why a narcissist's relationships are so meaningless. They lost the power of empathy when they retreated into themselves – they've never had the power to love anyone but themselves, because they never had anyone to love when their character was formed as a child. They enjoy the feeling of being loved, because this provides a source of supply to their real-self, but the false-self cannot love. It is an abstraction of reality, with a sole purpose; and loving someone does not fit this purpose. With such a desperate need to find love and attention for themselves, they do not have the power to give it away. By Freud's theories, it diminishes their own level of ego. In normal circumstances it would be replenished by the love from another, but this was not given when they needed it most, so they reverted to self-love, and lost the ability to love anyone but themselves.

It might be pertinent to explain the concept of 'self-love'. It is not really love, for the bruised ego in reality causes self-hate. Self-love is essentially self-centeredness.

So, destined to search for sustenance in the form of attention for all their lives, they try to gather networks of people who can provide, what I shall now term *Narcissistic Supply.* A lower ego (in the real-self) demands a higher level of supply, so they must do more to get a higher level of attention. Many narcissists lie, since it engages a certain level of rapture from their audience. Lying might be too strong a term, for a certain part of themselves believe the lie. This is known as the *grandiosity* of narcissists. They are able to soothe their battered ego by self-aggrandising; proclaiming to themselves, and the world, that they are something spectacular, they have amazing deeds to their name – living in a sort of fantasy world. This is a more extreme form of narcissism; where they cannot get through the day with the limited supply they receive. They always need more, and lying is a way to get it.

A narcissist can also collect a group of people who are good at providing supply – and attempt to receive as much contact with these people as possible. These contacts are usually low in awareness, because they are more likely to believe lies, and not see through to the agent's weak self. They are also people who the narcissist deems respectable, who conform to their own ideals; so that attention from such people is more boosting to their ego. In fact, the same works in reverse – they try not to have contact with people who do not reach their ideals, because their attention is substandard. In replacement of their mother-figure (the person who should have been central to their lives as a baby), they need to place worthy subjects.

Along with the group of *suppliers* (their 'primary contacts'), they may also seek a set of secondary contacts. This is the family. They are termed *secondary* contacts, because they provide a backup supply; people who can remind them of past victories, and bolster their ego when they are low. Children can also form an extension of the self – a way to live through another, and take their successes as their own. Unfortunately, a narcissist tends to overvalue and devalue family members in the same way as members of their primary contacts, and this can lead to the same cycle of neglect.

3.7.2 The Narcissism Parameter:

This is not actually a parameter in its own right. Narcissism is taken as a function of the Ego and Integration parameters. This is because neglect as a child leads to a level of traumatisation; and without a parent's love to validate their character, they fall into a pit of low self-esteem. The Ego parameter is selected to represent both ego libido, and object libido. In this way it can represent the splitting of the self.

Ego ranges between 0 and 1 – whatever value it takes is the agent's object libido. Hence, an agent who didn't receive much attention as a child would have a low Ego value. Because the agent effectively 'tops themselves up' with ego libido, we can assume that this ego libido takes the value (1 – object libido). Therefore, the agent always has a constant level '1' of ego, except it is split into its two forms.

A low ego by itself would just represent a self-conscious agent who isn't very confident. The splitting of the self occurs when the agent also has a low level of emotional health – i.e. 'Integration'. The low integration entails that the agent cannot cope with their inadequacy, and so revert to creating the false self. In this scenario, the object-libido component of the Ego parameter represents the ego of the real-self, and the ego-libido component represents the ego of the false-self.

I have determined that the cut-off point for integration where the two faces begin to emerge is at <0. The lower the integration is, the further the agent retreats into their fictitious, attention-seeking world. I have also decided that ego and integration, as two parts of a whole, bear equal weighting in the level of an agent's narcissism. Therefore, we can simply state the following:

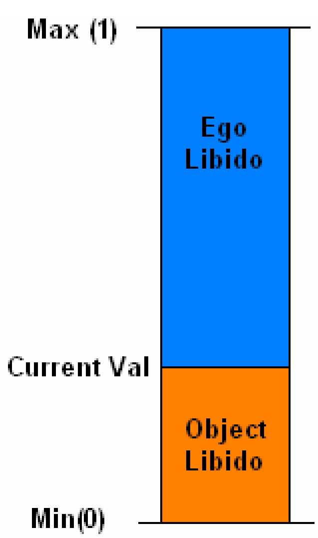


Figure 2.12. *The Ego parameter and its components.*

If (Integration>=0) {
    Narcissism = 0;
} Else {
    Narcissism = Integration*(Ego – 1);
}

The values of narcissism that are taken for varying levels of integration and ego are shown in Figure 2.13 and Figure 2.14 over the next two pages.

It's basic nature is simple, combining the two parameters in a way which gives them equal measure. The highest value of narcissism can only be taken by a single parameter combination (E=0, I=-1). The quadratic element provides a stretching effect, so that parameters with extreme values, bear substantially higher levels of narcissism than do the lower parameters. This reflects the abject mental state required for a true case of narcissistic personality disorder.

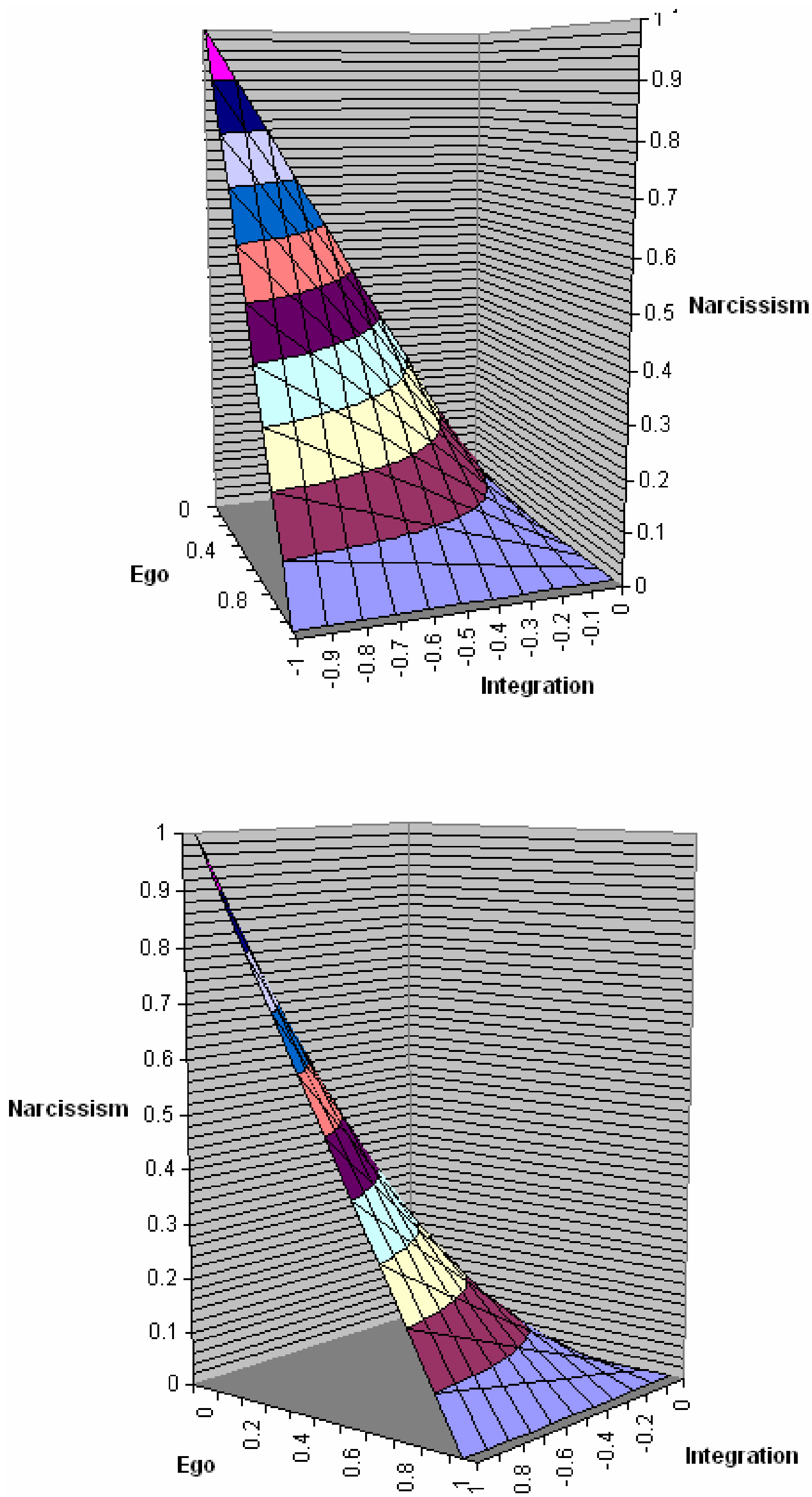


Figure 2.13. *Different Views of the Narcissism Space*

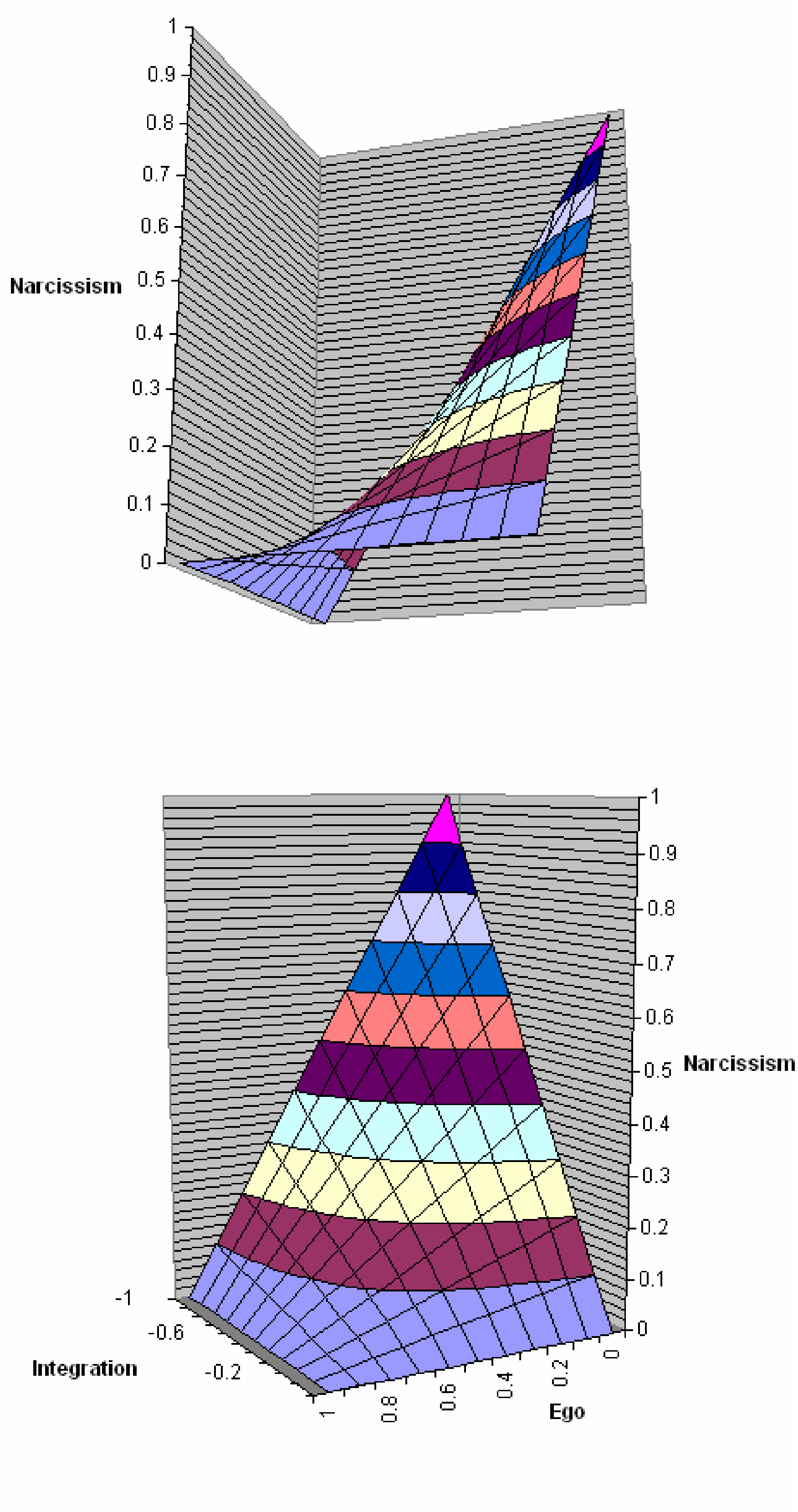


Figure 2.14 *Different views of the narcissism space*

3.7.3 Narcissist Features:

Narcissism is a unique condition that has a great deal of impact within a family environment, and unfortunately can cause a lot of damage. There are many different types of narcissist: the classic narcissist, pathological narcissist, inverted narcissist, thick and thin-skinned narcissists… But there are a couple of features which really form the core of this infliction.

3.7.3.1 Overvaluing and Devaluing People.

Because a narcissist does not really care for anyone (except themselves), they do not measure people based on their past relationships with them, or their good qualities. They measure people based on how they fit their own ideals. These can be loosely categorised to cerebral and somatic ideals (sporting ability and education - a narcissist will usually support one of these ideals far more than the other). It is therefore a very weak brand of relationship, which does not take into account the more fundamental aspects of the person, such as their ability as a friend. This quasi-relationship also stands true within the narcissist's family, whereby he will over/de-value his own family members; especially his children. If a child does not stack up to the narcissist's ideals, then the child will be thought of as worthless, or not worthy of attention. On the other hand, if the child manages to exceed the parent's expectations (which occurs infrequently), they will be over-valued: all the narcissist's attentions will be laid upon them. However, this does not occur in a healthy way. The parent will now try and control the child's life, becoming very authoritative. Both of these situations are far from ideal, because either the child is ignored, or they are not given control over their own life. An ignored child will have a low level of self-esteem, and may grow to become narcissist. This is also true of the over-valued child, who will be unable to create their own sense of self (through being forced to mirror the parent), and may find it difficult to integrate well into society as a result.

It is plain to see that a narcissist will push everyone they know to two extremes. Relationships are meaningless, and those who find themselves out of the narcissist's favour have to endure their wrath, or their cold shoulder.

I have simulated this over/devaluation of agents with the following function:

$$\text{narRelationship} = (1-\sigma)\left[\left(\sqrt{\text{ideal} - \text{performance}} \times 2\right) - 1\right] + \sigma$$

$$\text{where} \quad \boldsymbol{\sigma} \begin{cases} 0, & \text{if (performance > ideal)} \\ 1, & \text{otherwise} \end{cases}$$

In this equation, *ideal* corresponds to the narcissistic agent's ideal for either cerebral or somatic ability, and *performance* corresponds to the other agent's actual level of ability in this field. The square root is used to emulate the excessive nature of the narcissist's over/devaluing. This can be seen with the example in the table below. In this situation, the narcissist has an ideal of 0.8, and we can see how the relationship with that person varies depending on their performance level.

Performance	Ideal	Relationship
0.8	0.8	1
0.7	0.8	0.367544468
0.6	0.8	0.105572809
0.5	0.8	-0.095445115
0.4	0.8	-0.264911064
0.3	0.8	-0.414213562
0.2	0.8	-0.549193338
0.1	0.8	-0.673320053
0	0.8	-0.788854382

This relationship value is only true of the pathological narcissist, i.e. who is at the very extreme of narcissism. There are varying levels of narcissism, and this has to be taken into account. Therefore, a semi-narcissistic agent must weight in their *actual* relationship value (as described in the section 'Contact Lists and Relationships'), with the narRelationship value just calculated. This is trivially defined as:

*Relationship = (narLevel)*narRelationship + (1-narLevel)*ActualRelationship*

3.7.3.2 Need for Attention:

This trait is highly indicative of a narcissist, as explained in the introduction. The narcissist's extreme desire for attention is modelled in two ways:

- Selecting interactions based on which is likely to give the highest level of narcissistic supply, rather than the suitability for the situation.
- Artificially altering the agent's own parameters in a way that allows for maximum extraction of supply.

I shall now explain these in further detail.

3.7.3.2.1 Interaction Selection:

The selection of an interaction is usually determined solely by the mental parameters of the two agents in question, and their relationship. Remember, that one of these parameters was the narcissistic supply defecit of the active agent.

Narcissistic supply is calculated directly from the reaction the passive agent gives to an interaction. This reaction is essentially a level of attention given to the active agent – positive or negative attention. To the narcissistic agent, it does not make too much difference which he receives: negative attention is still attention, and that is the thing he craves. Even someone raging and storming with anger at them is someone paying attention, giving them time, and validating their existence. This means that a reaction of -1 provides the same amount of narcissistic supply as +1. A reaction of 0 provides no supply whatsoever, since it is effectively someone who is ignoring you.

An agent's level of supply is set to 0 at the beginning of each iteration – and during the course of the iteration, the agent has to attempt to achieve their narcissistic supply limit. This is a value which corresponds to their level of narcissism, i.e. a highly narcissistic agent will require more supply than a low-levelled narcissist. After each interaction, the agent updates their current level of supply. This is calculated as:

supply = supply + (reaction/numInteractions)

where *numInteractions* is the total number of interactions the agent will make during the course of an iteration. In this way, supply must take a value between 0 and 1. The supply defecit is therefore simply:

supply_defecit = supplyLimit – supply

An agent who has a high defecit is likely to pick interactions which usually produce a high level or reaction – like Fight or Lie. However, the 'ideal situation' for extracting narcissism which is described by these vectors do – by no means – reflect the level of narcissism that will be extracted, because they do not take into account the *individuality* of each agent. Therefore, for every agent they encounter, they need a way to determine which interaction will elicit the best response.

The agent does this by storing a history of each agent they have a relationship with, holding information about all the pair's past interactions. This takes the form of an *average* reaction to each type of interaction since the start of their relationship, and is stored in the Relationship Class.

Armed with this information, the max-levelled narcissist can make decisions based solely on their knowledge of what evokes the best response from their partner. By scoring each interaction based directly on the average reaction (which has been updated stochastically within the region *randvar*(-0.2, 0.2), assuming that perfect knowledge is unlikely), the agent is likely to have picked an interaction which will feed their supply.

Because there are differing levels of narcissist, this effect must be diminished accordingly; and the interaction which the circumstances describe as most relevant should also be taken into account. This gives:

*Interaction score = (narLevel)*C•I(Interaction) + (1-narLevel)*averageReaction*

(Recall that *C* is the circumstances vector, and *I* is a vector which represents the ideal situation for each interaction).

3.7.3.2.2 Artificial Alteration:

This is the process by which the narcissistic agent modifies their behaviour to get the best level of supply from their chosen partner. The more narcissistic an agent, the more falsely they will behave. Because the function of the 'false-self' is to obtain attention by all costs, it is usual for a narcissist's behaviour to be wildly different towards different subjects; especially if that subject is someone they deem respectable.

This is accomplished with a genetic-based algorithm, with phenotypes for each type of interaction. Basically, by storing which levels of their own mental parameters have induced the best reaction from their partner, they can modify their current parameters accordingly.

Before applying an interaction, the narcissistic agent will check the Phenotype for this interaction relating to the passive agent (two sets of Phenotypes are stored in the Relationship class; each recalling the other's behaviours). For a new contact, this phenotype genome is set to {0,0,0}, corresponding to {integration, awareness, ego}. This means that this genome is the best for extracting supply from this agent for this interaction. This is not strictly true to begin with; but these values are altered through time.

Therefore, whenever this particular agent is encountered, the phenotype for the type of interaction with said agent is found, and the genome is extracted. However, it is only through mutation that the state-space can be explored. Therefore, if the highest reaction so far has been taken when the agent's mental parameters had been at {0,0,0}, they will use this as a base level, and mutate all three elements of this genome by a certain amount. This is determined by the *evolutionRate*, which is an editable user parameter. The code for this mutation of the genome is as follows:

```java
public float[] getGenome() {
    //Mutate Integration Level, and perform bounds checks.
    genomeMutate[0] = Random.uniform.nextFloatFromTo((genome[0]-evolveRate)*1000, (genome[0]+evolveRate)*1000)/1000;
    if (genomeMutate[0]<-1) genomeMutate[0]=-1;
    if (genomeMutate[0]>1) genomeMutate[0]=1;

    //Mutate Awareness Level, and perform bounds checks.
    genomeMutate[1] = Random.uniform.nextFloatFromTo((genome[1]-evolveRate)*1000, (genome[1]+evolveRate)*1000)/1000;
    if (genomeMutate[1]<-1) genomeMutate[1]=-1;
    if (genomeMutate[1]>1) genomeMutate[1]=1;

    //Mutate Ego Level, and perform bounds checks.
    genomeMutate[2] = Random.uniform.nextFloatFromTo((genome[2]-(evolveRate/2))*1000, (genome[2]+(evolveRate/2))*1000)/1000;
    if (genomeMutate[2]<0) genomeMutate[2]=0;
    if (genomeMutate[2]>1) genomeMutate[2]=1;

    return genomeMutate;
}
```

Once the new genome has been found; the agents use it to update their own mental parameters, by an amount depending on their level of narcissism. If they have the highest level of 1, then they will take on the false parameters exactly. With a level of 0, they will keep their real parameters; and with a level between 0 and 1, they will scale their real parameters towards the false ones accordingly.

```java
artificialIntegration = integrationLevel + n*( genome[0]-integrationLevel );
artificialAwareness = awarenessLevel + n*(genome[1]-awarenessLevel);
artificialEgo = egoLevel + n*(genome[2]-egoLevel);
```

With this newly imposed mindset, or façade, they undertake the interaction, and observe the passive agent's reaction. If this reaction is better than the one which the original un-mutated genome represented, then this base genome is replaced by the mutant, and it's associated reactionLevel is updated. If the reaction is lower than the base genome, then it is kept to the same value, and used as the base for future mutations.

In this way, the agent is *constantly* adapting themselves to the passive agent, trying to govern their exact state of mind, learning how to play the agent as a puppet in their theatre of attention. This is an incredibly effective tool in the narcissist's repertoire,

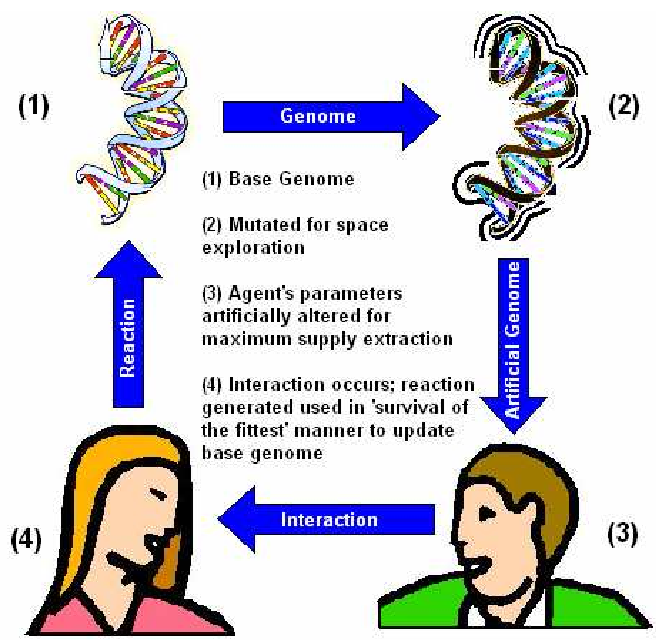


Figure 2.15 *Continual cycle of narcissists adapting behaviour to extract supply.*

3.7.4 Creation of a Narcissist:

The lifecycle of an agent is split into three main components; selected for their significance to narcissism. These are: *babyhood, childhood, and adulthood.*

3.7.4.1 Babyhood:

As described in the introduction, babyhood is a fundamental time when the deep-rooted beliefs about the self are created. This is therefore the breeding ground for narcissism. As a baby, there are not a great deal of ways to interact with the outside world. Motor skills are not developed, so physical intimacy cannot be initiated, and without the ability to verbalise themselves, there is no possibility of complex mental interactions. However, they *do* have a desperate need for attention, and they will often request this through crying – whether it be attention to their need for food, or simply a desire for loving attention.

I therefore have an interaction which is used solely by baby agents: "Request Attention." As I have already discussed, this is highly deterministic in the creation of narcissism in a baby; since if they are denied this precious attention, they become less integrated and suffer a loss of self-esteem. I have modelled this by allowing the baby to request attention a certain number of times a day. The parent who receives the request can make a decision between ignoring it completely, or attending to the baby whole-heartedly. There is no point introducing shades of grey in this interaction, because the baby is unable to discern between willing and unwilling attention. Therefore, it is all or nothing.

Whether or not the parent provides the attention, is decided by two broad categories:

- Selfish Reasons
- Unselfish Reasons

The former relates to the parent's level of narcissism, and hence their ability to empathise with the baby. Having no *real* affection for the child means that they are unlikely to shower it with attention and care for its needs – and so in this model, the request for attention would be ignored. The latter category of 'unselfish reasons' relates to the circumstances at the time of the baby's request. If the mother (or father) is rendered incapable of dealing with the baby, then the request would again be ignored. There are a number of factors which might make it impossible to deal with the baby. The first is the number of other children in the household, and their age. The more children there are, and the younger they are, the less likely it is the baby will receive attention. This models reality accurately, since *younger* children require more attention, and *more* children means splitting of that attention between them. i.e. in a household with:

- No other children: Baby receives all of the attention.
- 1 other child: Sharing of attention is (often unevenly) split in two.
- 2 other children: Attention values are split into three.

However, these figures are dramatically altered by the ages of the other children in question. If there is another baby in the household, then this will entail a full 50% split of attention. But if the other child is older (max child age considered here is 13), then that child is more independent, requiring less attention, which can hence be provided to the baby: so in fact, that baby would get 100% of the attention. The following formula considers all ages of children in the house, and all numbers of children present, in order to realistically model this factor.

$$\text{occupantFactor} = \left[1 - \frac{\sum \text{child.age}}{(\text{numChildren} + 0.001) * \text{maxAge}}\right] * \left(\frac{\text{numChildren}}{\text{numChildren} + 1}\right)$$

The parameter '*maxAge*' is set to 675 (~13 years old), to allow scaling of attention based on age. Note that children over this age in the household aren't considered in this equation; they have a level of independence high enough to allow the mother to concentrate on the baby. Also, numChildren refers to the number of *other* children in the household (not including the baby), and the *0.001* term has been used to eliminate the possibility of division by 0.

There are two other factors which could direct the mother's attention away from the baby. The first is her partner's level of narcissism. A narcissistic individual will not like the baby sucking up all the attention for themselves, and will try to engage the mother more often, insisting on attention, no matter how much the baby needs it. This is denoted as N_2 in the equation below. Finally, there is a stochastic factor, which covers all other possibilities why a mother might not be able to attend the child (for example, if the mother does not hear the child cry while she sleeps). This is denoted as *randvar*(0,1) in the equation below, since it takes uniform random values between the limits [0,1]. These three 'unselfish' factors are all given equal weighting by default.

The resultant affect is that attention is taken away from the baby. However, this attention-cutback can be diminished by the awareness of the mother (or whichever parent is interacting with the child). With a high level of awareness, they will know how critical their presence is to the child, and will make more of an effort to ignore these factors.

Taking the unselfish and selfish factors together, we arrive at the following equation:

$$P(\text{No\_Attention}) = (1 - N_1)\left[\frac{\frac{1}{3}\left(\textit{randvar}(0,1) + \text{occupantFactor} + N_2\right)}{1 - \left(\frac{\text{Awareness}+1}{2}\right)}\right] + N_1^2$$

As can be seen, the selfish and unselfish factors have been weighted with the requestee's level of narcissism (i.e. N_1). A certain level of simplification has been refrained from, so that the different factors of the equation are clear.

This calculates the probability of the parent not supplying attention. The final decision is therefore taken from the following probabilistic conditional:

If (*randvar*(0,1) < P(No_Attention)) {
    //IGNORE REQUEST
Else {
    //ATTEND TO CHILD
}

Over the course of the agent's babyhood, (between 0 and 150 iterations) it will make many requests for attention. The result of these requests are stored, and at the end of this period of babyhood, the average rate of response is taken. This determines their level of traumatisation, and their ego.

average = numAttentionReceived / TotalAttentionRequested.

Their new sense of Integration can be calculated as:
Integration = [average*2]-1

And the Ego simply takes on the value of this average:
Ego = average.

The reason for this is plain when you consider the concepts of ego libido and object libido discussed earlier. In my model, Ego consists of how much object-libido an agent has received, which is precisely what this average represents.

3.7.4.2 Limiting Hysteresis Cycles:

Simply setting these values of Ego and Integration for the agent does not suffice, because through the course of their interactions in the model, these values will change. It therefore would not reflect the *permanence* that this critical time in your life creates for your character. We need to reflect how hard it is to change such deeply-rooted insecurities.

I have modelled this by first deciding on how significant each stage of your life is in fashioning your character. There is some level of division between psychology academics on this subject. Some say that levels of self-esteem are set almost entirely within three years of birth, some say thirty percent within the first twelve months, others say only the *propensity* for low self-esteem is developed during the early stages and that childhood is the deciding factor.

I have therefore decided to split a person's life into three segments, and allow the user to decide the significance of each. As default, I have said 50% of the character is formed during babyhood, 30% during childhood, and the remaining 20% during adulthood.

Therefore, at the end of the babyhood stage, when the integration and ego parameters are initialised, it is necessary to limit the values they can take in the future. Because babyhood is 50% of the character, they can only change by the remaining 50%.

For integration, (topOfRange – bottomOfRange) = 2, therefore 50% of this gives 1. So, no matter what value of integration given to the agent at the end of childhood, they can only change it within a range of 1 for the rest of their life – i.e. a maximum of 0.5 movement towards the top of the scale, or 0.5 towards the bottom. Figure 2.16 shows this effect on the integration parameter. Based on the value they take from babyhood for this parameter (as calculated above), they can only move within a certain range for the rest of their life, indicated in the figure as the yellow area.

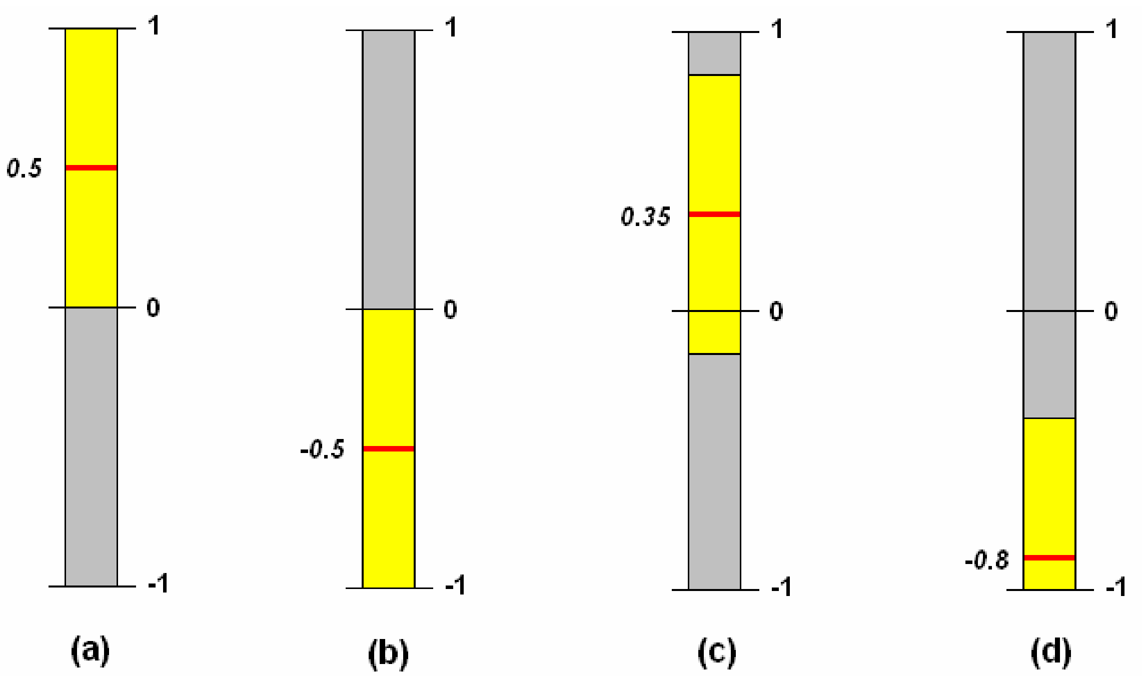


Figure 2.16. *Different values integration can take once childhood has started. The red line shows the value they were initialised with. (a) can take values between 0 and 1 (b) can take values between -1 and 0, (c) can take values between -0.15 and 0.85, and (d) can take values between -1 and -0.3. Notice that the available range does not shift itself upwards if the lower limit is exceeded. The same is true of the upper limit.*

Exactly the same is true of Ego, which varies between 0 and 1 (and therefore, with the babyhood significance level set to 50%, this parameter can only change by ±0.25). Be aware that the as the significance of a stage in life is reduced by the user, the yellow area shown above will increase. Increasing the significance will reduce this area.

As explained in the section ‘Updating the Parameters’, I added extra functionality to hysteresis cycles which allowed them to dynamically update their shape and size. *This* was the reason behind that decision. I can now simulate the permanence of a person’s character by altering the cycles’ limits.

3.7.4.3 Childhood:

When a baby enters into childhood, they are capable of interacting on a much more varied level. They no longer explicitly 'Request Attention'. Rather, they can get it through talking, or a number of other interactions.

This stage is less character-forming than babyhood, (though the user can alter the parameters to change this fact). Despite this, the parents are fundamental to the child's continued development, since the child still requires a certain level of self-validation. Indeed, the agent's self-esteem is still highly-malleable, so interactions during this phase are crucial.

Most of the effects of the interactions have been discussed already, including the effect on the agent's mental parameters. It should therefore be clear that there are a wide variety of scenarios which affect an agent's mental state, and hence their level of narcissism. However, there are some scenarios which are more likely to induce narcissism, owing to their damaging nature.

For example; consider the familial bonus placed on interactions with members of the family. This bonus augments the change in an agent's mental parameters, for both the positive *and* negative interactions. Accordingly, consider the damaging effect of a parent 'fighting' the child. This interaction already has a highly damaging effect; but along with the familial bonus, it becomes devastating. This is true of reality: physical abuse from a parent constitutes the complete destruction of the wall of safety and trust which the child has built around themselves. The level of the child's aggression will increase, and depending on their other parameters, they may well grow to repeat such behaviour with their own children.

Other forms of interaction will have a similar effect when it comes from a family member – e.g. Ridicule. But ignoring can be very damaging too, as I've made evident in the previous section. This same pattern continues into childhood, so it is important that the child receives adequate reaction when they attempt to converse with their parents especially. This is unlikely if there is a narcissist in the house, because they may well be devalued, and the false-self dictates that there cannot be a real relationship anyway. Even if the narcissist does find worth in their child, they will emotionally damage the child in another form: by trying to live through them. This takes the form of trying to control the child's life completely, from what they do and say, to what they wear. The child is never allowed to be themselves, leading to a slow but steady loss of integration.

Incidentally, because a 'Teach' interaction by itself is not at all harmful, we need a measure of the frequency of teachings. This takes the form of a 'teach limit', representing the maximum healthy number of teachings allowed in a period. This value is compared against the actual number of teachings after every 5 iterations. If the number of teachings exceeds the limit, then the a loss in integration occurs, scaled by the difference.

When the child becomes an adult, another 30% of their character has been set. Based on the average values of their parameters during childhood, we update the hysteresis cycle interval for a second time, effectively shrinking its range.

3.7.4.5 Adulthood:

By this stage in life, the mental parameters of the agents have been determined, and there is only a small window of opportunity for change. This 20% interval for change could be deemed their *Mood*. It is interesting to interpret their parameters in this sense; because if you look at babies, they go from one extreme to the next, alternatively crying and resting with satisfaction. A child's range is smaller, in the sense that they do not reach so far to the extremes, yet they still show their happiness and sadness much more easily than adults. These acute mood swings reduce as a person gets older; reflected by the hysteresis cycle ranges getting smaller; until they become an adult which has the smallest range of all; such that their emotional spectrum could be considered mood; rather than a change in the fundamental character.

As an adult, making the transition from non-narcissist to narcissist is highly unlikely; since the very nature of the infliction is that it is an intractable part of the person, imbedded deep within their character. The superficial wounds of adulthood cannot really produce narcissism, since the character has already formed.

Therefore, during this stage of life, the most interesting function of the narcissistic agent is their instigation of the narcissistic cycle in other agents – usually their own children. This is the *generational effect*.

4. Evaluation

The purpose of this chapter is to evaluate the results obtained within my simulation. This shall be referred to as the implementation portion of my evaluation, and it will be measured against the set of evaluation criteria outlined in section 4.1. Quantitative analysis is by far the most direct means of determining success and the significance of results, and so this shall incorporate the bulk of my assessment. However, there are other factors to be taken into consideration, which are harder to evaluate – qualitative factors, such as ease of use, reliability, speed, and aesthetics. These shall not be overlooked, although the criteria for their success shall be less rigid.

4.1 Measuring Success:

An acceptable project will accomplish the deliverables outlined in chapter one. These can be translated and summarised as follows:

> "*A system that simulates a society of individuals, operating within the structure of an abstracted daily routine, (including going to work, getting married and having children), in conjunction with emergent behaviour, and statistical data that can be displayed on a graphical interface.*"

A more ambitious project will attempt to deliver some of the extra features discussed; which could be described as follows:

> "*A system that simulates a society of family-oriented agents, with specific focus on the different types of relationships (i.e. parent/offspring, sibling, partner…), and the effect this has on interactions. Given different parameters, external effects and social dynamics, recognisable emergent behaviours should evolve on a macro scale, with some level of generational movement within, reflecting the powerful effect of childhood experiences on future generations. Narcissistic tendencies will evolve within the populous, in a way that realistically models its origins and its affects on agents of various relationships. Statistical data will be made available, such that global trends can be monitored, and agent history is easily defined.*"

These are very broad claims, and it will be necessary to verify accuracy through several different measures. This is unavoidable, because due to the very nature of complex systems, the definition of a comprehensive set of evaluation criteria cannot be explicitly stated – there is no single correct answer to a simulation. I will therefore be testing the validity of my model as outlined in the following section.

4.1.1 Quantitative Analysis

It is important to remember this model is experimental, so care must be taken when interpreting results.

- The behaviour of the society should be highly dependent on the parameters it is given. Changes in aggression, rates of parameter change, and different aspects of the model specifics (such as removing agent self-modification), should be the seminal factor in the manner of emergent behaviour observed.

- These results should translate pragmatically to situations discussed in chapters 2 and 3, both on a global and on a local level. Global levels of change are much more malleable to supposition, but should reflect the fundamental aspects of the implementation. Local levels of interaction should correspond to realistic human behaviours, definable by the mental parameters of those agents involved.

- Human societies exhibit many complex behaviours which could be considered chaotic, but there also many aspects which (without external effectors) stablises over time, or exhibit constant change. For example, consider the average test score in the English education system, and its gradual rise over the decades. Without external factors such as governmental grants and information-accessibility with the advent of computers, this rise would most likely cease. Consider the consistent significance of fashion in high society, over the course of hundreds of years, or the cyclic behaviour of mass 'morality' during times of war and peace. I shall therefore be looking for a certain level of stability in my model, with respect to initial conditions, (in terms of fixed points and repellers). I will also heed any cyclic or chaotic behaviour with reference to their origins.

- I will examine patterns and trends in terms of global changes in the state-space, and patterns in the parametric space. The extra dimension of generation-space will also be considered for transmission of familial elements (specifically narcissism) down the family line.

- Because of the non-deterministic nature of the system, different runs of the simulation based on the same initial parameters will produce different results. It will be necessary to perform re-runs to ensure reliability and validity of each result.

4.1.2. Qualitative Analysis:

As I have mentioned, there will be several performance-related measures that will need to be taken – these can be considered assessments of correctness rather than accuracy; and are necessary if we consider the utility of the simulation in outside hands. If results are meaningful, but they cannot be obtained without explicit instruction by the creator, or appear in a form which does not aid understanding, then the final product is devalued. The measures I shall consider are as follows:

Robustness – The simulation should not allow the user to enter invalid or out-of-range results, specifically for parameter initialisation. The systems should be able to run autonomously without any errors, for any set of input data.

Quality – This refers to the whole experience of human-computer interaction. The GUI should be easy to use and intuitive. Data representations should be relevant, easily accessible, and should display data in its most easily analysable form (for example, consider the difficulty of handling complex networks of relationships throughout the model, and how to navigate between them). The GUI should be aesthetically pleasing, and should aid understanding.

Efficiency – The simulation consists of a number of ticks – i.e. iterations within the populous, whereby agents perform a set of activities. To observe the evolution of the society, it can be necessary to wait for a great number of ticks, and therefore speed is essential. It is understood that larger systems (in terms of number of agents) should result in longer iterations; though this growth should be minimised. This has been done to some degree with a series of optimisations; some of which have already been discussed.

4.1.3. Testing

During the course of program-creation, I have tested my system in a number of ways, to ensure correctness and continuity. For example, with the inclusion of a new method, *Unit testing* was undertaken to make sure that output was correct, exceptions were dealt with accordingly, and input parameters were valid. This was particularly important with the implementation of new facets of narcissism. It was important to check the impact on the system of these inclusions to discern any undesirable effects, and that behaviour was computed as it should be. (For example, checking that mathematical functions always presented valid results was always imperative). I also undertook *Regression Testing*, to make sure that additional software functionality did not produce regression bugs, which occur when previously working code no longer results in the desired behaviour, as an unintended consequence of program changes. By re-running previous tests, I was able to detect whether previously fixed faults had re-emerged. Finally, after the implementation was completed, I undertook *System Tests*, to check the behaviour of the entire system against its specifications. It is this form of testing, in essence, which shall make up the bulk of my evaluation.

4.2. Overview:

Over the preceding chapters, I have explained the model and how it works, and it is time to relate the results I have obtained within it. My evaluation shall consist of a brief summary of outcomes for several different aspects of my system.

These shall focus on the following:

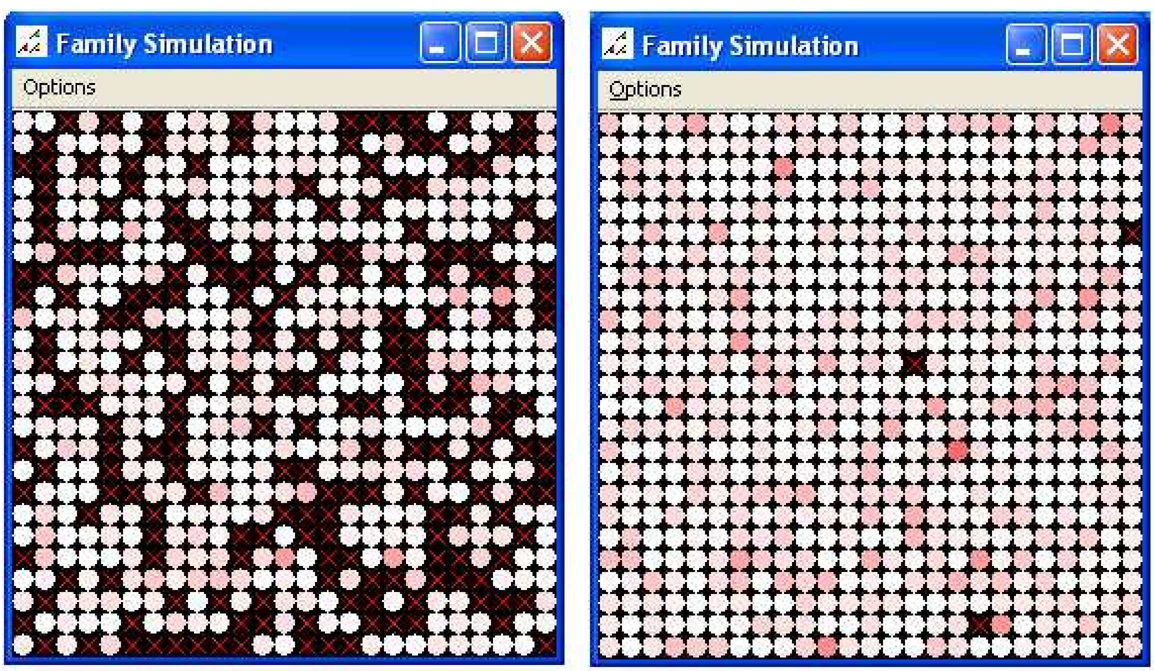
- Different implementations.
- Characteristics of narcissism.
- Emergent phenomena (global) relating to the society as a whole.
- Family-specific (local) emergence.

4.3 Population Dynamics

The population of the system is very dynamic, in that it has a number of different factors that controls it. Agents autonomously spread throughout the system, creating new family sub-systems, populating the artificial world based on a married couple's relationship, their current number of children, and space in the world around them for the new child. It is common for population control to be forced upon a simulated society through explicit hacks, though I wished to create my society from the actions of individual agents alone; with no global behaviour being written or forced *at all*. I was extremely pleased with the results of my efforts, because through agent individuality alone, I was able to glean exactly the results I had hoped for; in a way which realistically reflects natural ecology. Figure 4.1(a) shows the state of society at the beginning of the simulation. The crosses represent empty houses, whereas the circles show houses which have between 1 and 5 occupants. Since the agents in the system are initialised with artificial values to represent all cross-sections of society; at time step 0 there are already agents ready to move out. As can be seen by Figure 4.1(b), empty houses are quickly moved into.

Figure 4.2 shows some of the system output - a brief glimpse of movement in the city, including marriage, birth, death and the acquirement of a new home. We therefore know that agents are interacting in such a way that they wish to populate their earth, and find mates, and so forth. Without this, the population would die (in Japan, for instance, grandparents outnumber grandchildren because the birthrate has fallen to 1.3 babies per woman - well below the minimum replacement rate of 2.1).

Figure 4.3 aptly shows the movement in population size, in a way which is reminiscent of the predator-prey model discussed in chapter 2.



(a) *State-space after 0 ticks.* **(b)** *State-space after 76 ticks.*

Figure 4.1. *Population filling up the city over a period of ~1.5 years*

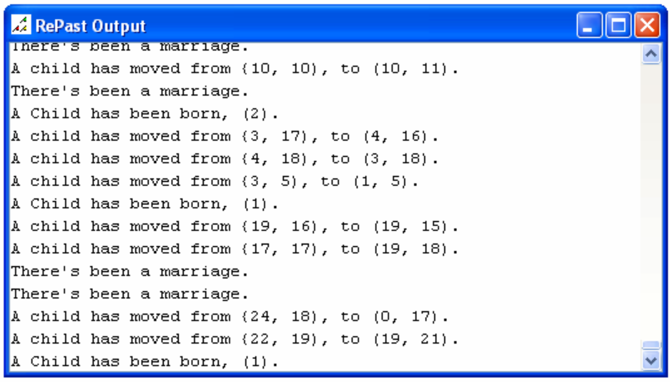
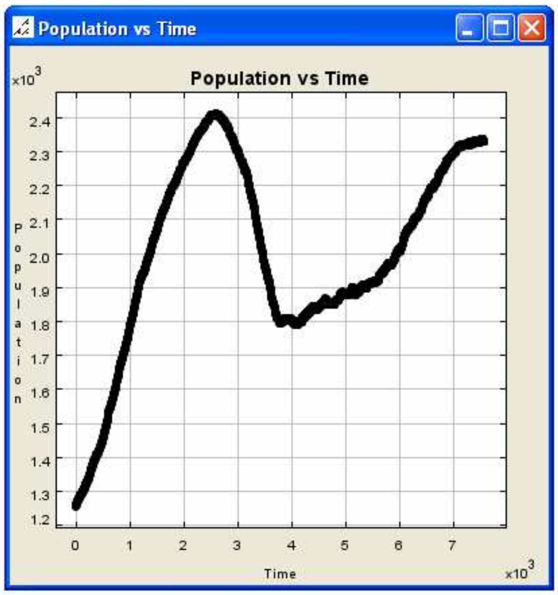
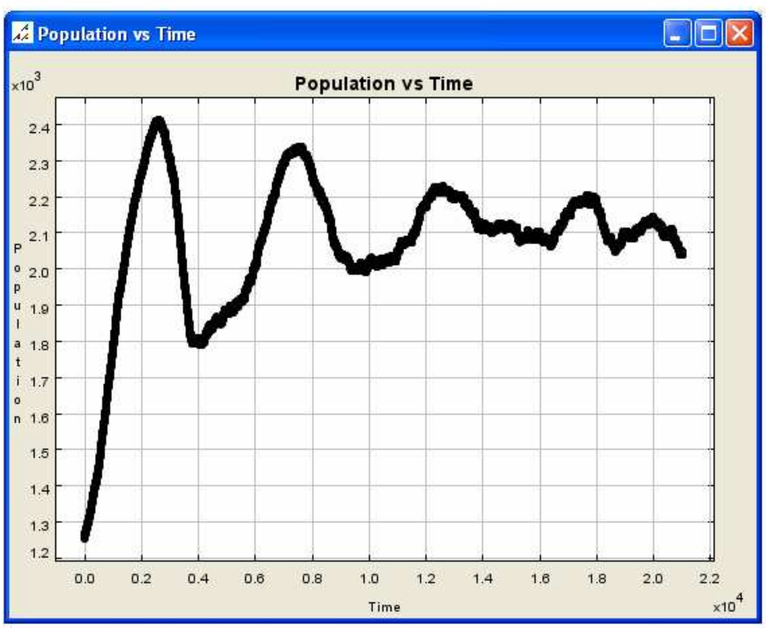


Figure 4.2. *Population dynamics - constant system output describing the movement of agents within the city.*



(a) Population change after 7000 ticks



(b) Population after 23,000 ticks.

Figure 4.3 *Population dynamics of the system at different stages of operation.*

The reason for this cyclic behaviour can be explained as follows: when the population reaches a peak, there is limited space in the environment (cf. overcrowding, competition for resources. When considering humans in an enclosed environment, think of job competition, and the resultant poverty). Therefore, when a population reaches a limit, it finds that there is no room for more agents, and so new couples cannot emerge. The number of offspring starts to decline, hence the appearance of troughs in the chart. However, when the population decreases to a certain extent, the few children who remain can grow up to leave their parents' house and have their own children, with ample space to do so. And so the cycle continues.

There is one key difference to the predator-prey model. Rather than cycling in a manner which reaches the extremes during each rotation, the cycles get smaller and smaller, until it converges to a fairly constant value. This is typical of human societies. There is generally no huge fluctuation – on a global scale, population stays pretty constant. In reality, we could consider its gradual rise, but we must remember that the world is an environment with an almost unrestricted space for its inhabitants (there are still many vast areas of land yet to be occupied), whereas in my model, there is a definite finite limitation for number of agents. Therefore, convergence to a specific value is the most appropriate behaviour one could hope for.

4.4 Simplified Model

In my first example, I shall be using a much simplified version of reality; a basis to be built upon. In it, there are two simple actions, *talk* and *fight*. They are two basic counterparts, a duality if you will, which correspond to pro-social and anti-social interactions. It should be noted that they do not necessarily represent talk and fight interactions; these are just broad decisions for bad or good behaviour against a neighbour made by an agent. In this way, we can distinctly apply mood and relationship into a steadfast action: an extreme counterpart.

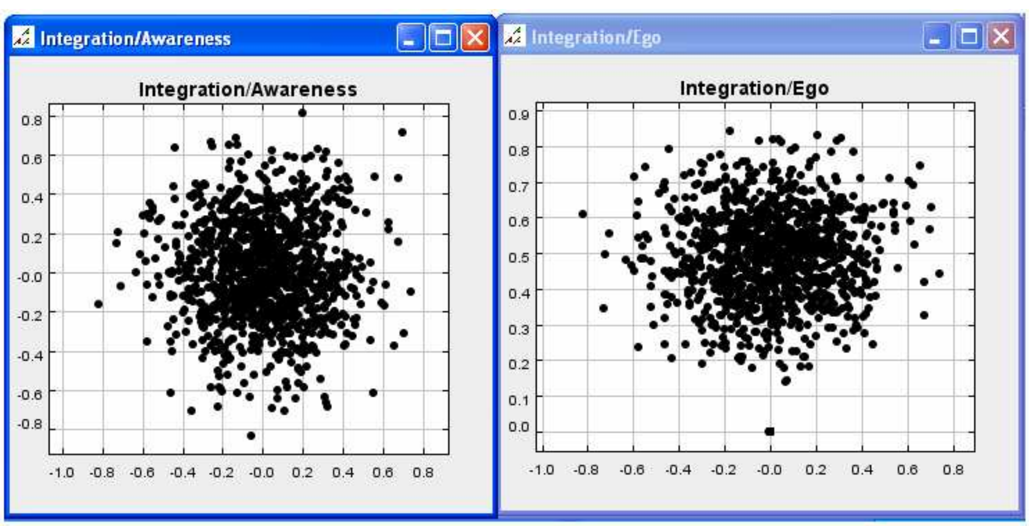


Figure 4.4 *Initial parametric space for all agents in the system.*

As can be seen by Figure 4.4, the initial setup is respondent to the Gaussian parameter distributions described in Chapter 3. (Integration corresponds to both charts' x-axis). All agents have been assigned mental parameters within the distribution, so that the population centres around a neutral point (0 for integration and awareness, and 0.5 for ego). This has been done so as to not give way to potential bifurcations, owing solely to the initial setup. As discussed, complex systems such as that I am creating are very amenable to sensitivity to these startup conditions. For example, if the average population were all low in integration, there may be fixed points which they are drawn towards on the negative spectrum – meaning that behaviours representative of highly integrated individuals are not covered in the simulation. Individuals who might betray typically pro-social behaviours and the accordant emergent behaviours that would entail, would not be able to demonstrate this ability. The initial configuration of agents would instead lead to a mass-manoeuvre towards the negative spectrum. This is a very important consideration when considering simplified models such as this one, because extreme behaviours easily lead to extreme results.

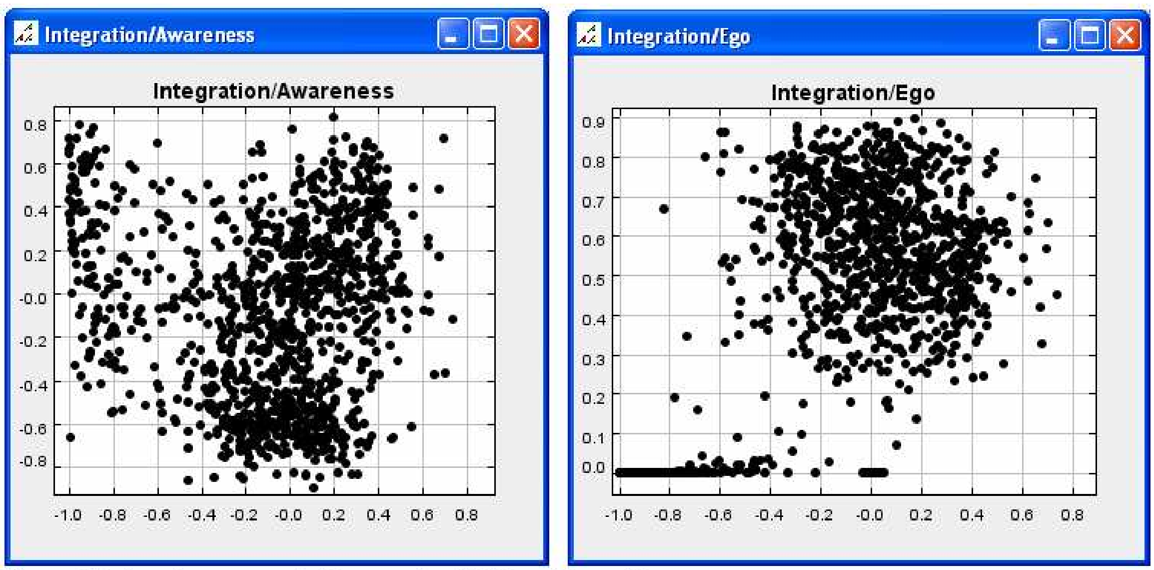


Figure 4.5. *Mental parameters of all agents after 133 ticks of the model.*

This model does not take family-specific relationships into account – all agents are treated as one and the same (it just so happens that some of them live within the same household). Age is also not considered in this model. The development of an agent as a child is no more significant than during adulthood – therefore, an agent potentially has the ability to switch between extremes during its lifetime.

As can be seen in Figure 4.5, trends in agent mental faculties are already beginning to appear. Specifically, we see a subset of narcissists appear (see bottom left corner of the Integration/Ego graph – remembering that a narcissist is the product of a low integration and a low ego). They consist of the agents who were born into the system with narcissistic tendencies, which were unfortunately exacerbated by fights with other agents. Note that both a fight directed towards oneself, and also towards another can lead to a loss of integration and ego in this model – so therefore a narcissist is likely to drag other agents down towards their own level. For an agent with an already fragile ego, this will be disastrous: this is actually what we are witnessing here, the clash of narcissist on narcissist. Losing emotional health owing to consistently fighting, they descend downwards in a spiral of repetitive action – since a low integration entails more chance of deciding to fight rather than to talk in future interactions. Repetition of this behaviour leads to a group of extreme narcissists, honing in on a fixed point of (I,E)=(-1,0). On the whole however, it is a pro-social society that prefers to talk over fighting. This is evidently seen from Figure 4.6; a snapshot of the society after 1000 iterations.

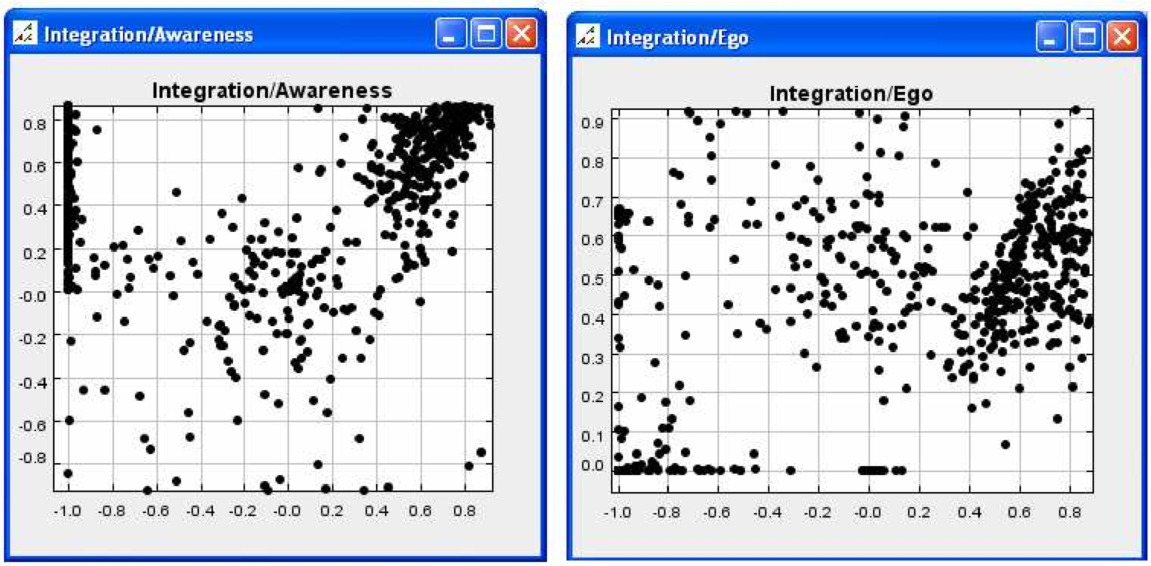


Figure 4.6. *Agent parametric space after 1000 ticks.*

It is the extreme behaviour previously described which converges the society so quickly towards such clusters. The society, on the whole is highly aware – an affect of *talk*ing. Only a very damaged agent prefers to fight over talking; which is natural. Consider the number of people talking in the real-world compared to fighting. Even at times of war, camaraderie has a strong attraction to most people. As awareness increases, the desire for talk increases, which feeds back into levels of awareness. We are quickly led into an almost utopian society of highly integrated and aware individuals; with only a small subset of narcissistic personalities, (i.e. we have fixed points at the opposing extremes of narcissism). This is particularly evident in Figure 4.7, after 8000 iterations.

Most interestingly, we see a very peculiar relationship emerge when comparing integration and awareness levels of the agents. Parameters for every agent land on the graph of y=x. It took a while to work out the cause for this strange behaviour – but it is a result of agent birth neutrality. Born as agents are in this model with a clean slate (i.e. nature is not pre-ordained), their awareness and integration parameters are set to zero. This, combined with the effect of being born into an almost completely pro-social environment (where negative actions like *fight* are outweighed roughly 27 to 1), results in agents who will always talk. The majority of their interactions are set to be with their parents during early stages of life, so agents are drawn towards positive behaviour by their parent's pro-social influence. Since the talk interaction leads to a symmetric increase in awareness and integration, this leads to the graph of Figure 4.7. It is therefore important to accept the significance of agent origins on future global behaviour. An agent needs to be defined at some point by some specifics of their parent's influence…this cannot be measured by such extreme attitudes as this model portrays. The subtleties of interaction need to be taken into account, and therefore the available types of interactions needs to be diversified. In addition, an element of external feedback needs to evolve, so that not only do agents *act* within the system; they also *react.*

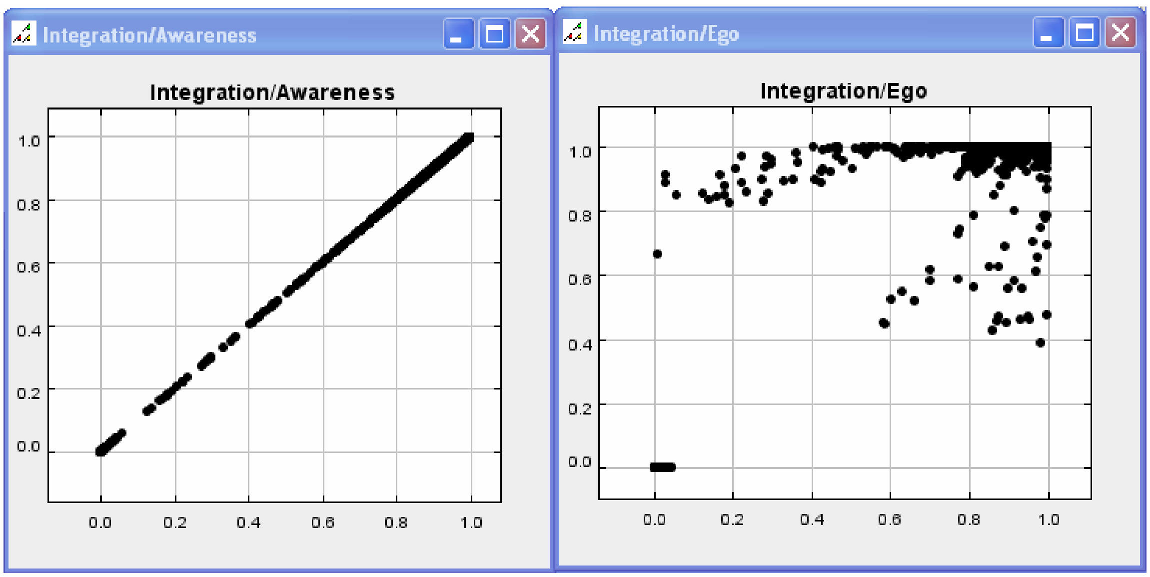


Figure 4.7. *Agent parameter space after 8000 ticks.*

4.5 Interaction Diversity and Reaction

The addition of further interactions to this enhanced model allows for the dissipation of such extreme behaviour; and the ability to be born into a society whose overlying philosophy is not so united (as in the previous case). This leads to more realism in terms of agent individuality, providing a broader scope for the results. Also, allowing agents to react differently to a situation based on their mental parameters and the relationship in question, effectively extinguishes update based continuities (as was obvious again in the previous case).

Some of the effects of these additions to the model can be summarised in Figure 4.8.

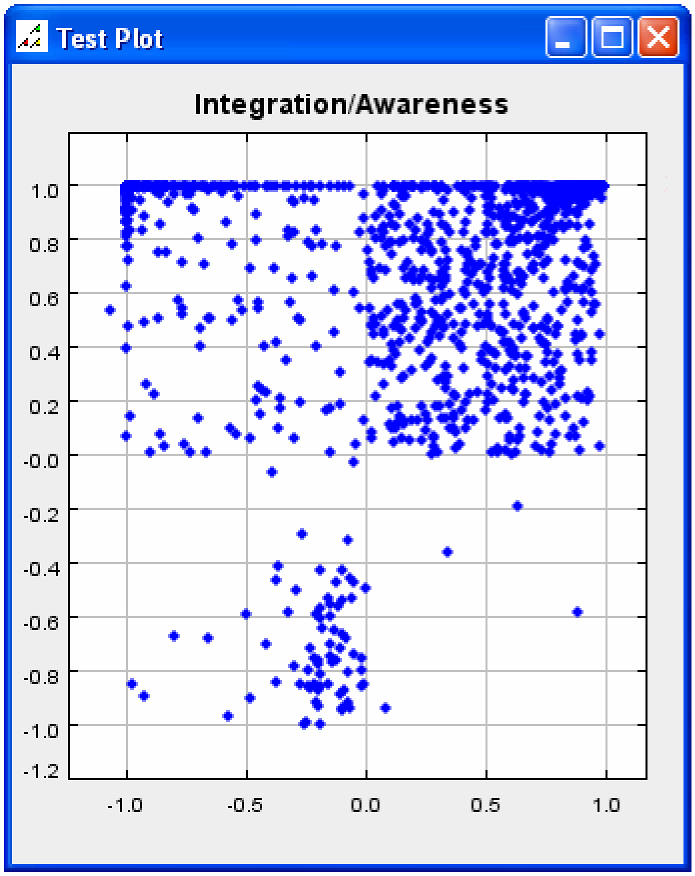
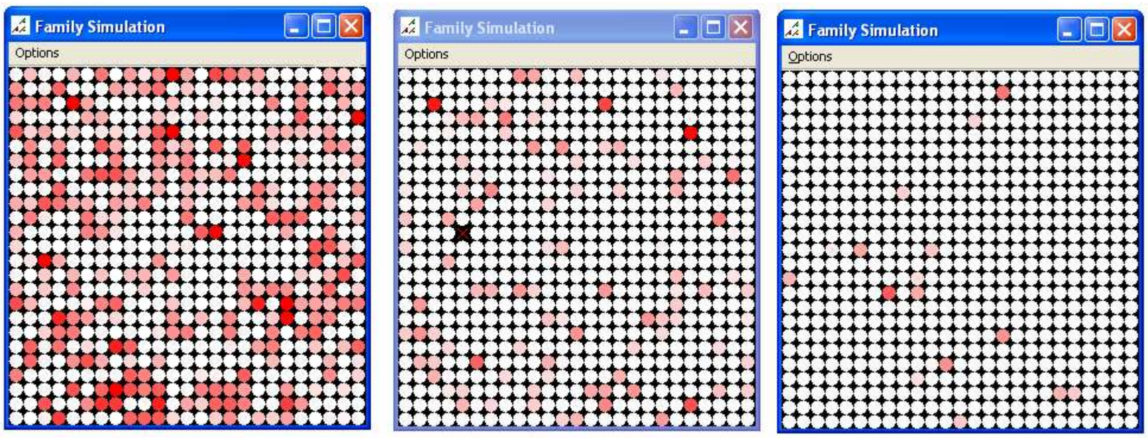


Figure 4.8 *Parameter space at 3000 iterations*

The diversity of response can quickly be gleaned, with agents spanning a much broader area of mental states. However, distinct grouping can still be observed. In the upper right quadrant, we have the agents who are both integrated and aware, spread evenly over the entire space. This is where the majority of humans would place themselves – a differing level of positive integration and awareness. There is also a distinct group of narcissists, in the upper left quadrant (all flitting towards the extremes of the disorder). It is their influence which creates the third group in the lower left quadrant – the inverted narcissists. Their emotional health has been abused through repeated ridicules and fights with the narcissistic agent; hence their correspondingly low integration.

Interestingly, we find very few agents in the lower right quadrant. It appears that agents with high integration and low awareness are few and far between. This can be explained by the fact that narcissists in my model are more likely to use agents with low-awareness as tools for extracting narcissistic supply (as previously discussed). The narcissist's interactions will gradually wear down their victims' integration levels until they are forced into the emotionally damaged group in the lower-left quadrant.

During the course of the simulation, the global level of narcissism is diminished, as shown in Figure 4.9 and Figure 4.10. The former shows the state-space of the city (with each circle representing a household – higher shades of red denotes a higher average level of narcissism within the household). It is interesting to see the clustering visible from as early as 2000 iterations. Those households in the direct neighbourhood of a narcissist are more likely to feel the effect of this narcissism. This is because I have not limited parameter ranges – owing to childhood experiences – in this version of the model. Agents still have free rein to switch between extremes (hard to do, though not impossible), and so adult agents can feel the effect of the narcissism, and become correspondingly narcissistic as a result of injury. The lighter shades of red consist of those households which have indirect influence from neighbours. The darker shades of



(a) 2000 iterations (b) 6000 iterations (c) 23,000 iterations

Figure 4.9 *State space displaying narcissism at different points of the simulation.*

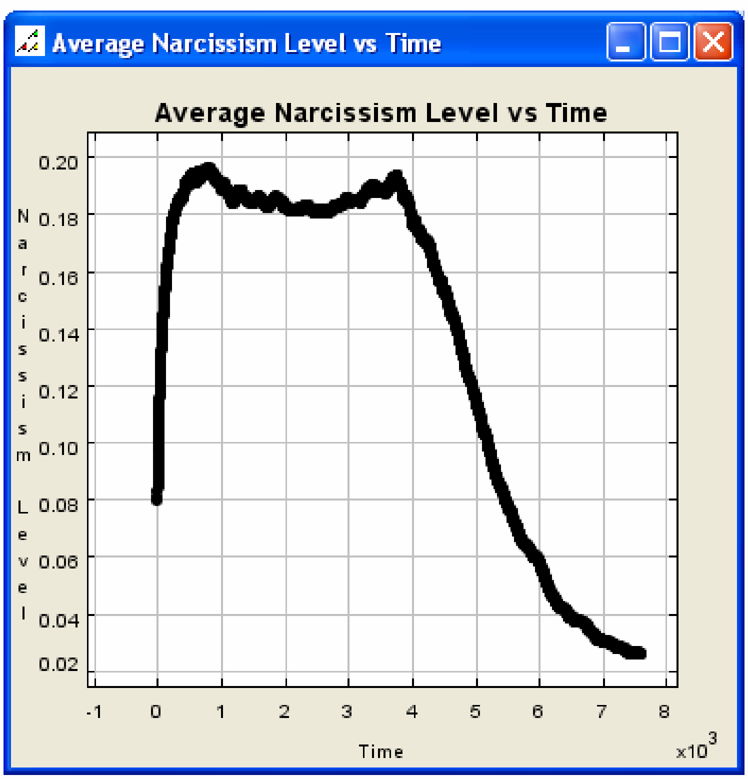


Figure 4.10. *Change in narcissism levels over time*

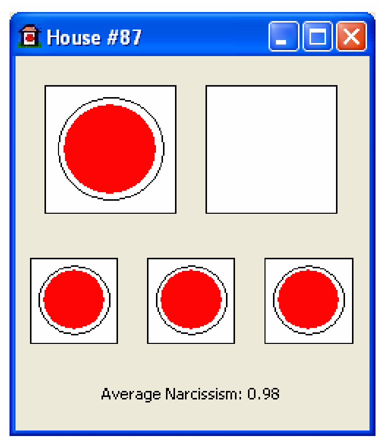


Figure 4.11

A household, within which a narcissistic parent has inflicted narcissistic injury on their children through mistreatment.

red are from narcissistic personalities inflicting their rage and ridicule against their own family members; and hence, we already begin to see the emergence of the generational spread of this trait. For instance, we can see from Figure 4.11 that a narcissistic parent has consistently mistreated its children to such an extent that the children have in turn developed narcissism.

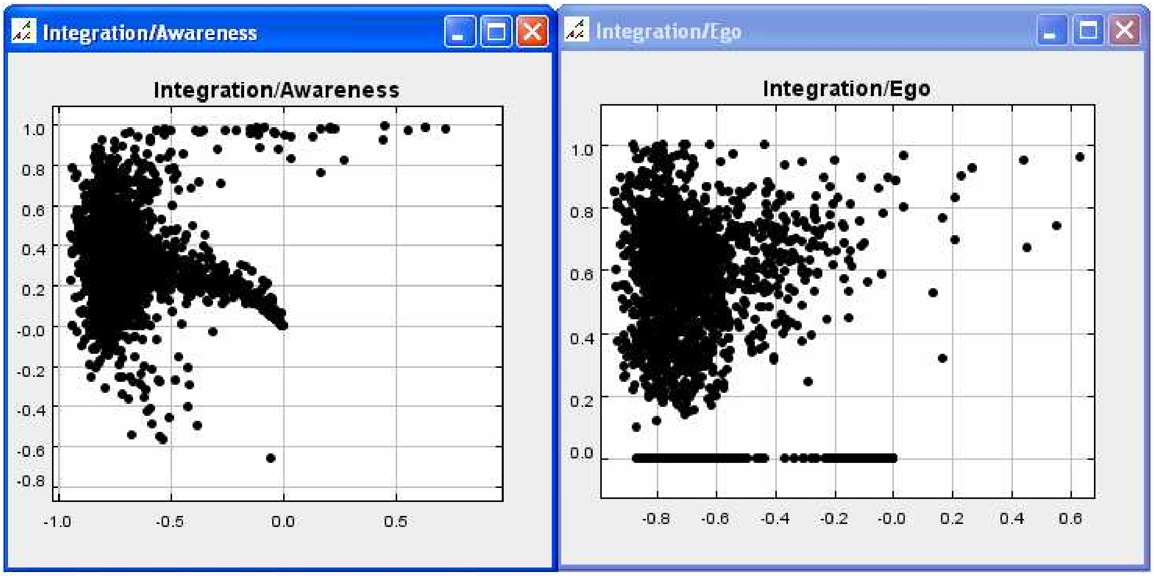
At 23,000 iterations however, we see that narcissism has diminished drastically. With no specific significance laid on family interactions as yet, the effect of narcissistic parents is engulfed by a host of other interactions which take place at the school and office. However, narcissism never disappears altogether. The levels shown during previous iterations are as a result of initial conditions; therefore this is merely the transient phase. The system settles with a relatively stable level of narcissism – which, as can be seen – is quite low. This reflects society fairly well, since there are a low proportion of truly pathological narcissists; but we can still see the dire effects on a family of a narcissist's presence (i.e. the consistently dark red households displayed).

Despite this, we would not expect to see such extreme, direct transmission of narcissism as shown in Figure 4.11, and its effects should be a little more widely spread. Indeed, if we wish to see true generational spread, the nuances of the family relationships will have to be explored. Other major factors which have not been included in the model are aggressivity and authority of parents, and over/de-valuing of agents.

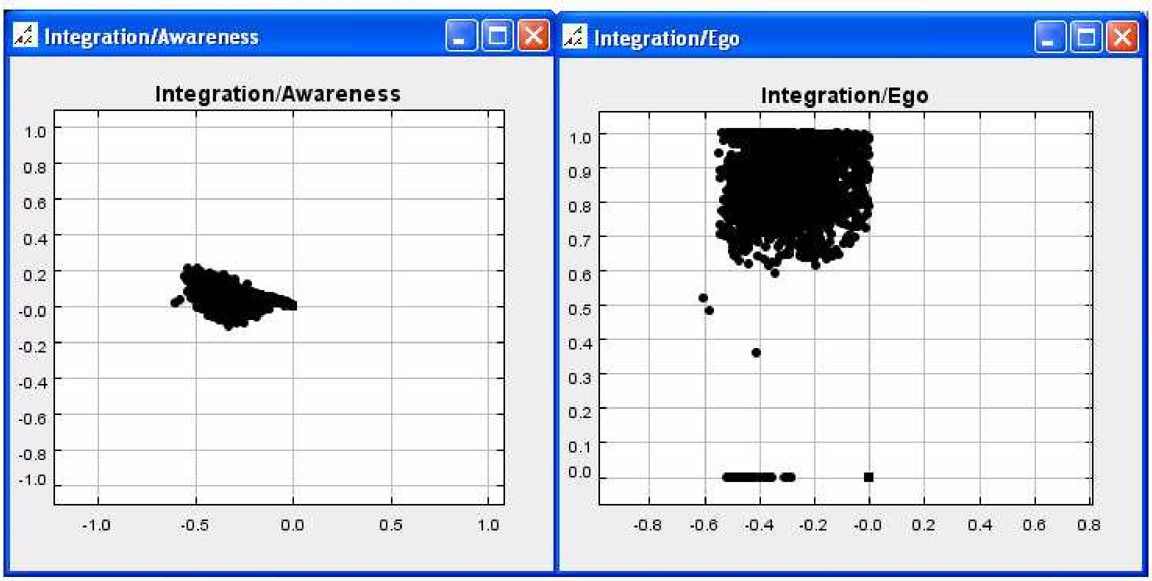
4.6 Hysteresis Cycle Amplitude Modification

This is an example of a type of parameter which can be altered in the model. This affects the degree by which all agents update their parameters, and can be independently modified for each parameter in question. Namely, these are Relationship, Integration, Awareness and Ego. The effect is quite drastic on the size of agent clustering, and can also be updated for individual agents to model erratic behaviour (agents able to change their emotions quickly and severely – i.e. temperamental or even schizophrenic agents), and passive characters, who are quite impervious to the positive and negative effects of human interactions – e.g. cold/unemotional people, or even those who have withdrawn within themselves for self-protection.

Figure 4.12 shows a society which has undergone the external affect of high traumatisation, and also the corresponding affect when the magnitude of modification of all four parameters are condensed by a factor of five. Vastly different outcomes are evident, which do not only shrink the agent parametric space, but can also have the effect of shifting agents to entirely new global levels. By changing the rate at which a parameter changes, you also affect which interactions are going to occur in the future. This is because each parameter is scaled by a differing amount during agent updates. Hence, the state of each agent changes accordingly. These parameters can also be altered to model the differing propensities for change for their respective mentalities (e.g. some would say that a relationship is much more malleable than a person's level of integration).



Before hysteresis cycle amplitude modification.

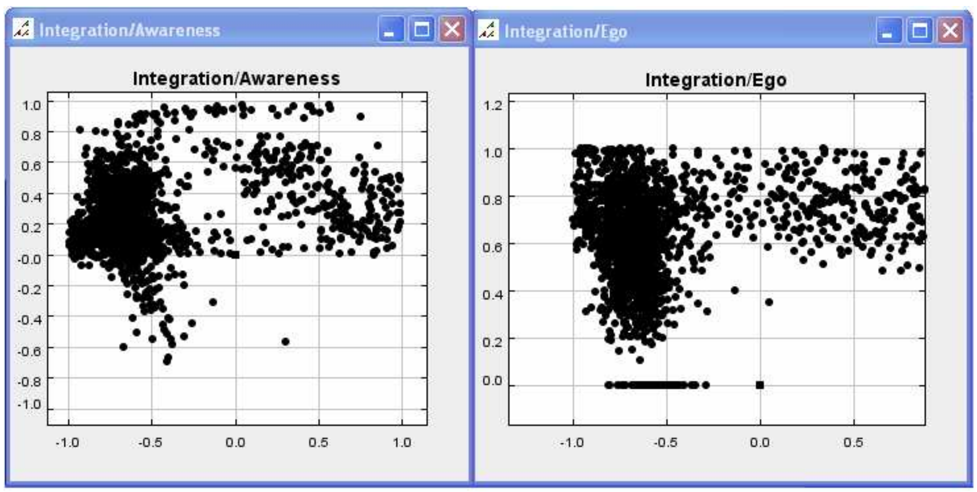


After the four editable parameters have been truncated by a factor of 5.

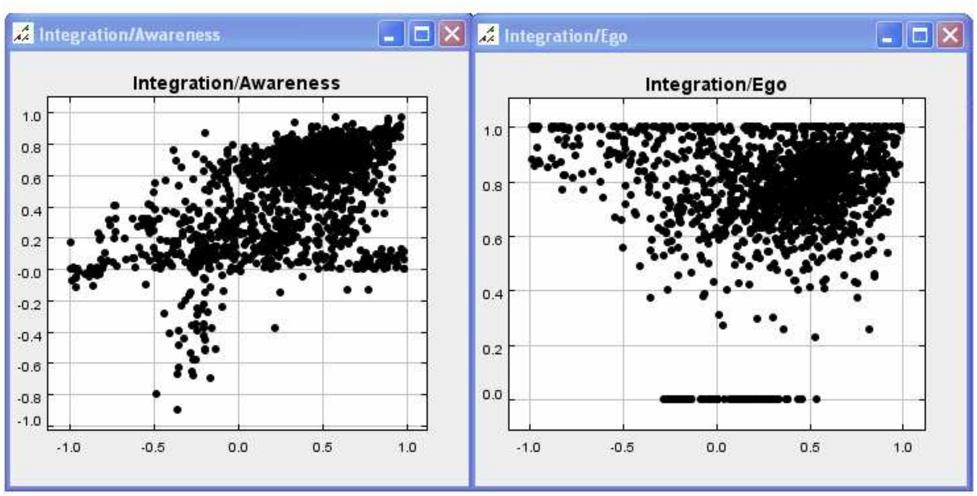
Figure 4.12 *The affect of altering parameter amplitudes on the parametric space of the agents.*

4.7. Aggression

Here, I shall briefly consider the affect of introducing aggression into the model, as one of the effectors of narcissism. Agents are not born with an aggressive propensity; rather they acquire it through interactions with other agents – specifically *fight*ing. Every time an agent is assaulted by another agent, their level of aggression increases. This affects the level of 'ferocity' of future fights they may have, and the resultant mental injury this will cause other agents. This injury will be greater between family members – particularly parent-offspring relationships. It is easy to see how significant physical abuse is to the emotional development of a child, which is portrayed as shown in Figure 4.13. Here, I have artificially set (using one of the model's editable parameters) the average level of aggressivity within the system. With a high level of aggressivity (see Figure 4.13(a)), agents have more of a desire to fight, and hence they inflict narcissistic injury on other agents. This cycle is likely to be repeated in the affected agent if it occurs consistently (since his aggression levels will rise). The result is that the entire society will transgress into a state of emotional traumatisation; and as can be seen by the



(a) Average aggresivity at an artificially high setting.



(b) Average aggressivity at an artificially low setting.

Figure 4.13 *Changes in agent parametric space based on average levels of aggressivity in the system.*

Integration/Ego chart of Figure 4.13(a), this will create a whole generation of narcissists (especially considering that the effects of fights are greatly increased when applied to a relative). The entire bulk of society become narcissistic to some degree, a pattern which is likely to be recreated in their children. Conversely, with a global state of low aggression, the ferocity of fights are decreased, and hence the iniquity created in the receiver is too. Agents are more likely to talk (or compliment etc), and the whole society transcends into a state of well-being. These effects on interaction selection can be seen quantitatively in Figure 4.14. There are almost as many *fight*s as there are *talk*s in the former society, and considering that the effect of a fight is much greater than a talk, it is easy to see how great an affect this can have on the entire system.

These examples have shown the extremes of aggression, so that its effect on individual agents' actions can be discerned. Authoritarian parents betray similar characteristics, although it displays itself with excessive teachings, which thus leads to an increase in their childrens' propensity for an authoritarian nature, rather than an aggressive nature. This is another sure road towards a loss of integration (and even narcissism).

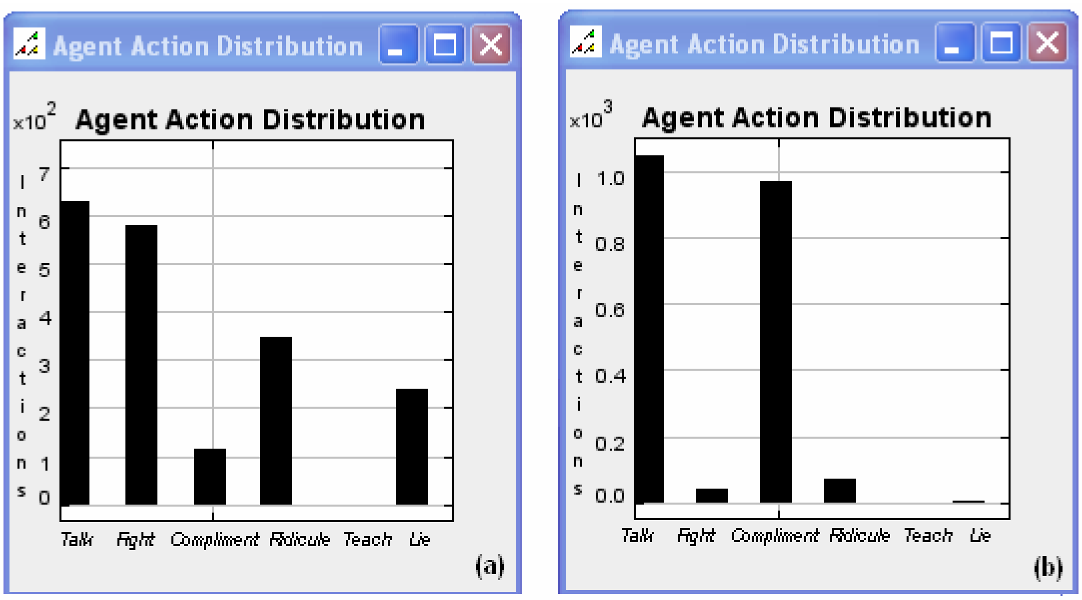
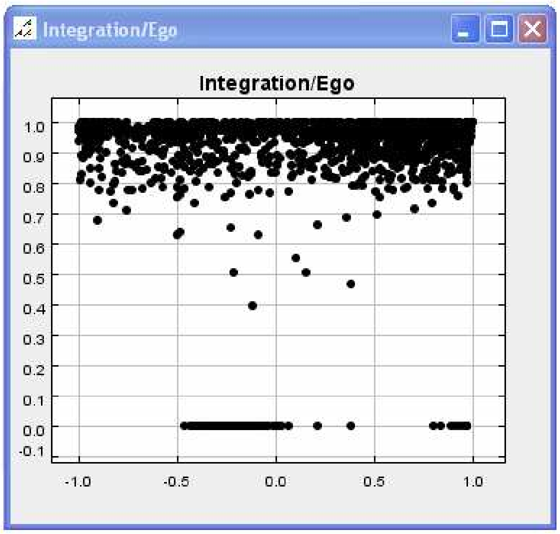


Figure 4.14 *(a) Relative levels of interaction in a highly aggressive society.* *(b) Levels of interaction in a state of low aggression.*

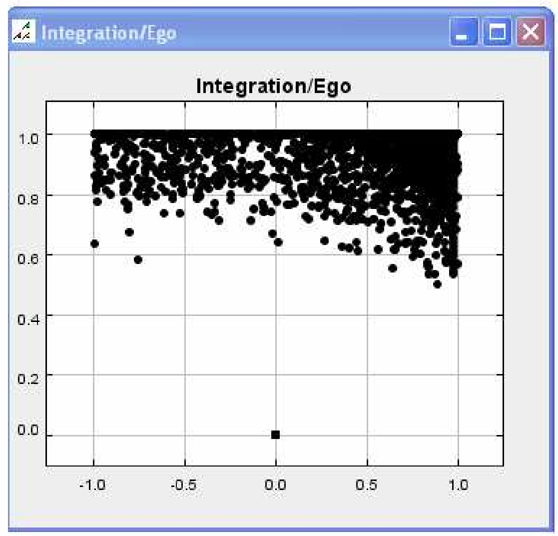
4.8 Character Formation

During the formative years of childhood, interactions with the parents are a large factor in deducing an agent's propensity for narcissism. The method by which this has been modelled has already been described; but I shall quickly recap. Interactions during babyhood and childhood are the most significant periods of an agent's life in the formation of their character – and so I have reflected this by emphasising the importance of the interactions within these periods. These are centred around the levels of love and attention received from the parents. By weighting the three periods of life in my model by 0.5, 0.3, and 0.2, I have effectively limited an agent's capacity for change, and hence the significance of their stages in life.

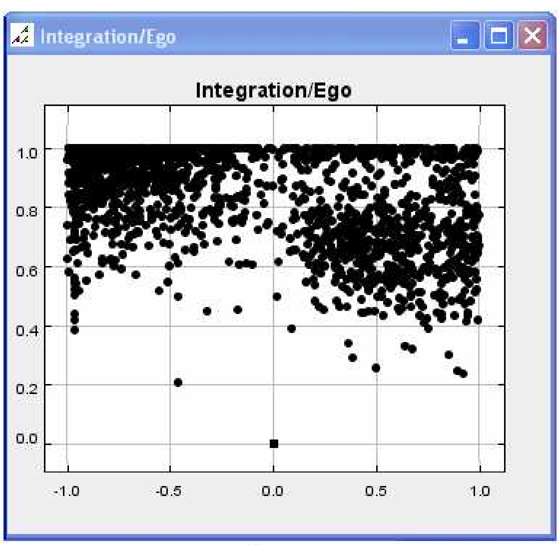
My results relating to levels are narcissism are show below:



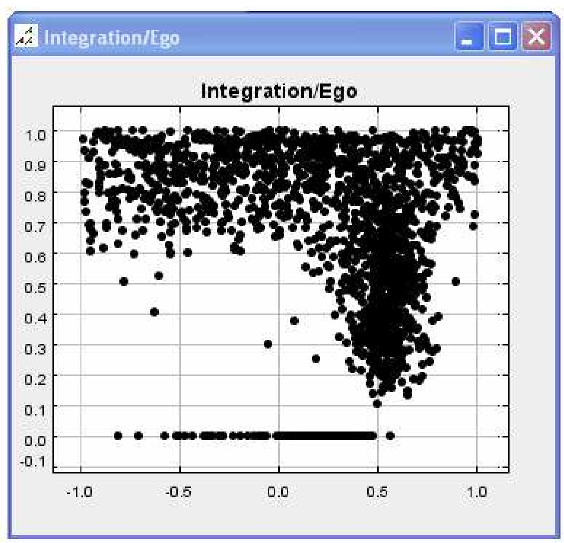
(a) 0 ticks



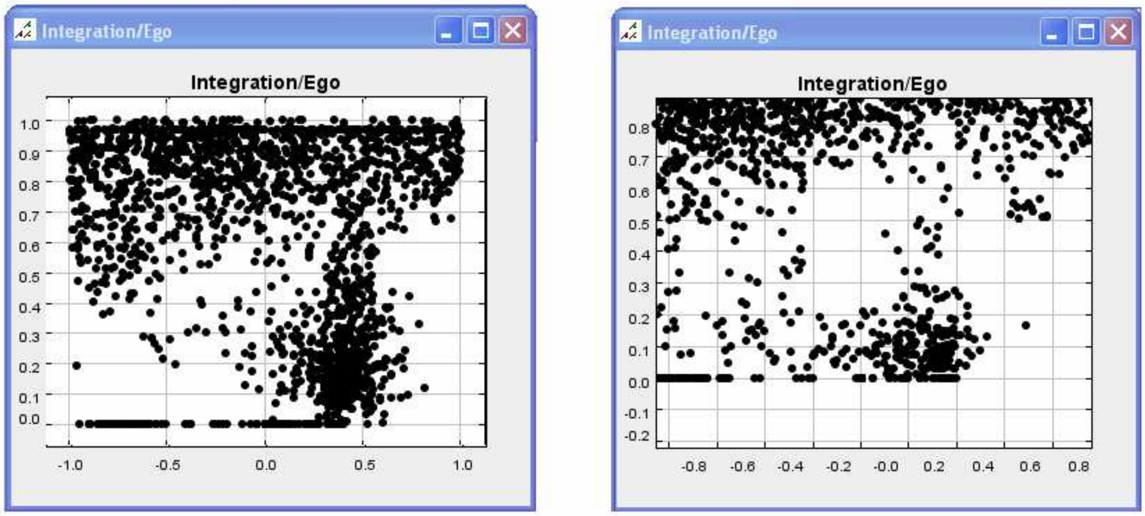
(b) 300 ticks



(c) 800 ticks



(d) 4000 ticks



(e) 6000 ticks (f) 10,000 ticks

4.15 *Evolution of system with character formation taken into account*

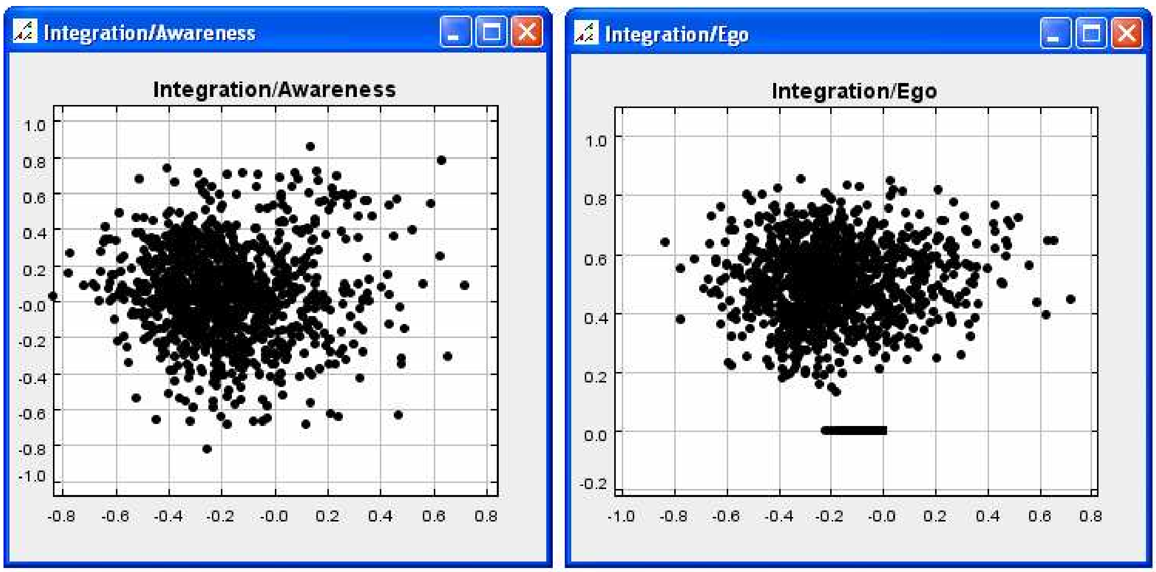
This complex behaviour is very interesting. By starting the society with a majority of agents with healthy-egos, we are able to see their decension into narcissism – and the fact that narcissism can be created from neglectful non-narcissists (though the affect is somewhat greater with a narcissist family). The transient phase of the system portrays a shift of the demographic as agent parameter initialisation is superseded by results from the system itself. This takes the form of many agents entering childhood after differing treatments from their parents during babyhood, (owing to the spread in the values of integration of the parents as evident in (a), among other factors). This accounts for the newfound spread of egos emerging. In this model, new-born infants are given an integration spread over a distribution, though in further models this has been related in part to the attention received as a child. As ego-levels drop, the propensity for narcissism increases – and so we get a new generation of parent narcissists. They in turn are likely to have behaviours which will badly affect their children – and in the right set of circumstances (considering all the other factors mentioned above), their narcissism will spread to their children. This is the reason for the cluster towards the bottom of the chart. This behaviour will remain fairly constant over time (though different runs of the model produce slightly different results), in a cycle of narcissism reproduction. Generational memory is evident. However, notice that this is only a subset of the population - and apart from the extreme narcissists (of which there are mercifully few), we have groups of healthy agents displayed too.

4.9 Global Traumatisation and Counselors:

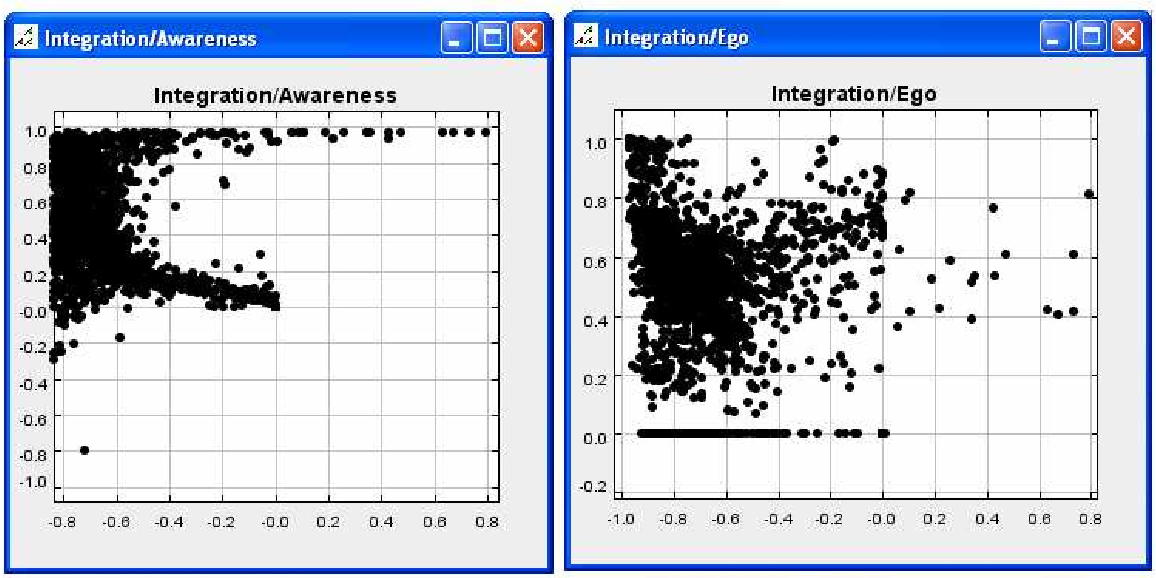
At this point, I shall briefly present the results for mass-traumatisation and mass counseling. Firstly, I have unleashed a traumatic event on the entire city, in the matter of an instant – (in terms of reality, one could consider such catastrophes as Hurricane

Katrina, and Chernobyl – both of which have had long lasting effects). As Figure 4.16 demonstrates, the otherwise healthy society is pushed to the extremes of traumatisation (i.e. low integration) – and the tail towards it shown in (b) are the future generations following the same path as their parents. With the influence of that traumatisation on their parents, their upbringing is wrought with trauma too from neglect and lack of love.

It takes a long time to heal the population, with many generations of anti-social behaviour and some extreme narcissists, but it eventually returns to a stable state within 3000-4000 iterations.



(a) Healthy population of individuals before mass-trauma event.



(b) Agents after mass-traumatisation

Figure 4.16 *The effect of mass-traumatisation on a previously healthy society.*

Mass-counseling has a similar affect (see Figure 4.17), in that it pushed integration towards the positive extreme. It can (in part) restore the health of a mass-traumatised society. However, unlike mass-traumatisation, counseling is much easier to deteriorate from (consider how some people need years of counseling to recover from a traumatic event, whereas a recovered alcoholic can far more easily fall back into alcoholism).

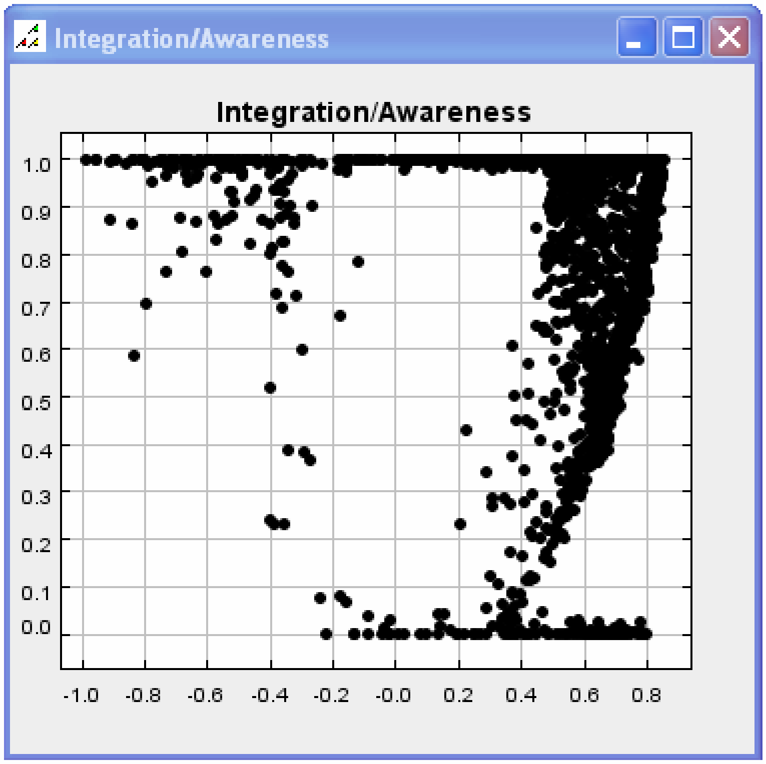


Figure 4.17 *The effect of mass-counseling on the population*

4.10 Generational Spread

I have introduced a number of different means of determining the spread of narcissism among the contacts of an agent, and particularly within a family unit. Because of the complex nature of the different relationships and their significance, it has been quite a feat to create a system capable of displaying relevant data pertaining to relationships in an easily accessible manner. However, I have accomplished this with the Family Tree window, and the Relationship window.

First of all, I will show you a typical example of a household containing a narcissistic agent (see Figure 4.18). As can be seen, there is a pathological narcissist among a household of lesser-narcissists. It might also be plain to see that the lesser-narcissists are an effect of his interactions with the rest of his family. However, one must consider that even a pathological narcissist will not be able to induce a high level of narcissism from an otherwise healthy adult – therefore the other parent must have also sustained previous damage (perhaps exacerbated by their partner). Their affect combined is far more significant on their children who are in a formative stage of their lives (their high narcissism levels can be seen in Figure 4.18 – where a darker shade signifies a higher value). The parents, as narcissists, are more likely to withhold attention from their children; effectively starving them emotionally.

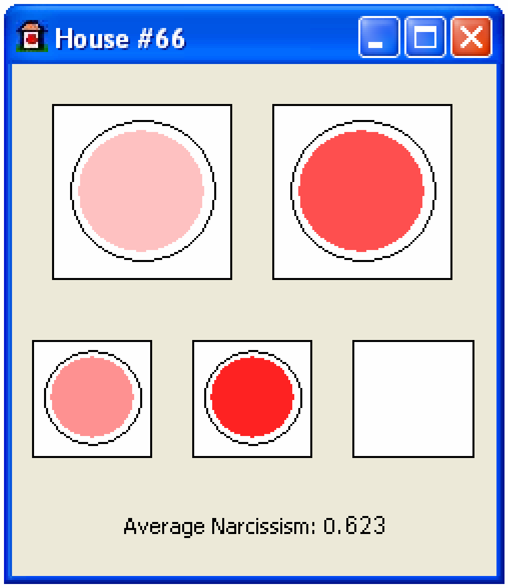


Figure 4.18 *A 'Narcissistic' Household*

We can see how this narcissism was created in the children by entering their relationship links (from individual agent view). From here, we can see all of the agents' contacts, and their relationships to them. In this view, white refers to neutral feelings, red to feelings of great affection (increasing with shade), and green referring to feelings of hatred (with darker shades indicating stronger feelings). In the case of the most narcissistic child shown above, their Relationships can be seen in Figure 4.19. It is clear to see the root of their narcissism. By selecting an agent within the window, details of past interactions between the child and this agent will be shown in the interaction history pane (alternatively, current interactions can also be shown). As can be seen, her narcissistic father paid her little attention during babyhood, and for the rest of her life so far, he has beaten and ridiculed her. Remember, this is the behaviour of an extreme narcissist, who (according to his history) also had a build up of aggression from a childhood full of fights.

The result of both his effect in the family environment, and the vital influence of the mother, is to create a child who has almost no self-esteem and is extremely traumatised. She took that through the rest of her life (though incidentally, owing to a future husband with a low level of awareness, but also zero-narcissism, her own children suffered, but were saved from the extremes of the disorder).

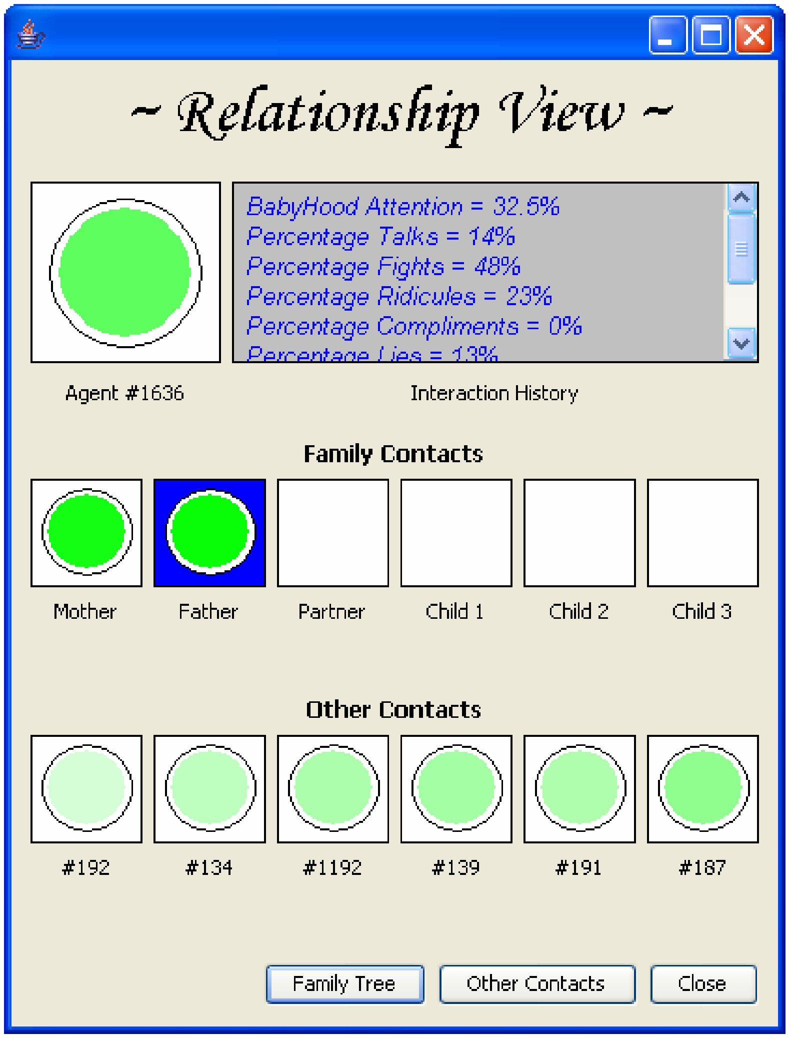


Figure 4.19 *List of agent contacts, and links to past history descriptions, and current interactions*

I have demonstrated the emergence of narcissism being passed through children within a family unit, but what about considering the longer term affects of this disorder (and hence, the influence of a family?) Does its effects pass multi-generationally, and if so what is a typical run-length? Well, this is an extremely hard measure to quantify, since the effects of narcissism come from so many different factors – including authoritarianism, aggressiveness, childhood history, levels of narcissism in parent figures, and a huge number of non-deterministic interactions within the family and without – all of which have influence over the generational spread of the disorder. In essence, a complex system creates complex behaviours, even with a trait as solidly defined as narcissism within this model; and therefore every family will have their own unique behaviour.

It is this individuality which could be considered to represent realistic behaviour; since no family's interactions in real-life will ever produce identical dynamics. However, since this project has taken somewhat of a focus on the effects of individual agents on their environment and society; a good measure would be to look at the effects of one fully pathological narcissist on subsequent generations, with no other narcissistic influences (i.e. the agent's partner would be non-narcissist, the agents children would marry non-narcissists, and so on…) This has to be artificially applied, since this particular situation would be probabilistically very hard to come by in the natural course of the system – and since its evolution cannot be predicted, one would not know where to start the search.

By applying this artificial lineage at the appropriate stages of the system (i.e. before a child has chance to choose their partner), and by doing so for many different pathological narcissists in families all over the system, I discovered that the average run-length of narcissism through generations was 3.125 (generations) before it completely disappeared. This is not indicative of actual run-lengths, which have more narcissistic input, but it is a good measure of the power of an individual agent over future generations; and how, through appropriate circumstances, these effects can reverberate throughout time for much longer.

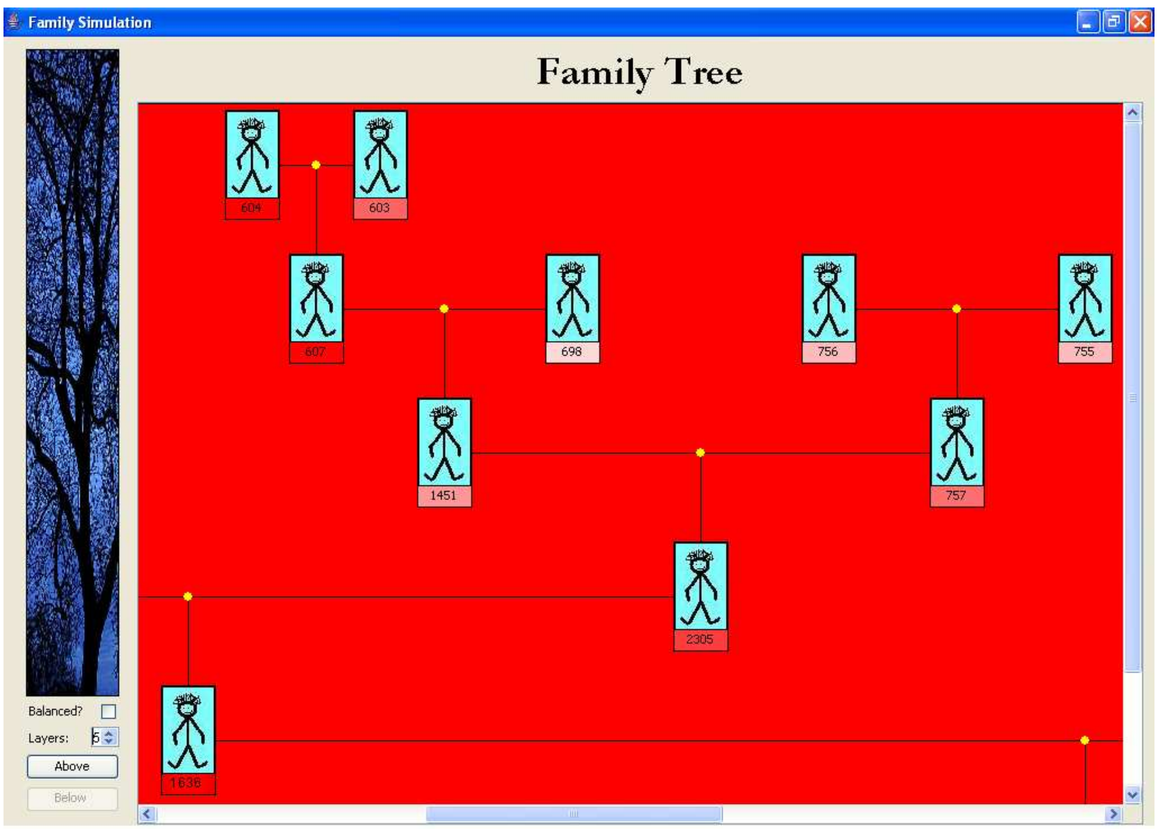


Figure 4.20 *Family Tree for agent 1636.*

Figure 4.20 shows a powerful tool I created for the recording of an agent's family tree – up to ten generations forwards and backwards. The agents ID's are shown underneath the pictures of the blue-agent images, and their level of narcissism is reflected by the shade of red surrounding their ID. This tool was created with space considerations deeply in mind (in order that speed would not be affected, and so that no matter how many iterations had passed, agents histories could still be recorded). The scroll-space can get very large with up to twenty generations show on screen at once (and up to 2^n agents on a single row above the central agent, and 5^n below). However, many agents either don't produce children, or don't reach the maximum number (of 5), so with some careful tree pruning algorithms this space is dramatically reduced. Each agent also acts as a hyperlink to their own family tree, and a list of statistics. The family tree shown in Figure 4.20 is a section of the family tree belonging to Agent 1636 (whom we have been considering throughout this section).

4.11 Quality Testing

This analysis was conducted as a test on ten computing students, and five students from other faculties. The model's target audience include both computer-literate engineers, and social scientists, hence my selection of testers (i.e. non-experienced users are also included). I asked each tester to use my model and its different features, and rate it on a scale of 1 to 5, over four broad categories: *Ease of Use*, *Reliability*, *Efficiency*, and *Aesthetics*. The results are shown in the table below.

	1 (lowest)	2	3	4	5 (highest)	AVERAGE
Ease Of Use	0	0	2	9	4	**~4.1**
Reliability	0	0	0	1	14	**~4.9**
Efficiency	0	1	6	4	4	**~3.7**
Aesthetics	0	0	2	3	10	**~4.5**

The model measured well on all counts; especially reliability. The lowest score was on efficiency – owing to the memory intensive nature of the simulation. The testers found the system intuitive, easy to use, and visually appealing.

5. Conclusion

Human social systems are one of the most fundamentally complex systems studied by science. Levels of complexity stack on top of each other within even the simplest situations; from the organisation of cellular activity, to the emergent phenomena behind collective neuronal behaviour, to the state of an entire society of individuals.

It is impossible to predict the evolution of such a system. And yet, with the advent of computers and the subsequent capability for simulation, social scientists around the world are attempting to do just that, and more. Theoretically, a rich enough model could predict a society's reaction to any clearly defined external event. For now, we know that through simple abstractions of reality, we can broadly define complex systems, in such a way that some of their behaviours are still apparent. That has been the purpose of my model.

The objective of my project was to model a society of individuals that interact within an enclosed system – a society. Specifically I attempted to model narcissism and the notion of family structure. It is clear that approximations to actual situations are rife with the complexities that such systems entail – and yet some good first-order approximations were obtained. Through evaluation of certain aspects of my model (some were omitted owing to space and time considerations), it was possible to observe a certain level of realism behind a narcissist's actions, and also on the effect of a family's influence through time.

However, in its present state, my system clearly cannot be used to make any real predictions on a society's behaviour. Indeed, too many notions have been discluded: these include economics, the power and control of leaders, social organisations (discluding the family structure), international communication between nations (a further level of complexity), religion and many other factors which are pertinent to a society's evolution.

If I were to enrich my model further in order that it could be used more practically, I would firstly consider parallelising all algorithms, so that the system could be split into functional units; each operating under a single CPU. The most obvious resource would be the model's agents. However, this would be extremely wasteful of processing power. (Perhaps one day, if enough facets of individual and social behaviour were included, this would potentially be necessary). A much more amenable candidate is the splitting of the simulation into more than one city. Further, this could give rise to country-wide and even global interaction. The fundamental point of this consideration is to witness the effect of external factors which are not imposed explicitly by the user. External influences which arise from other social structures would add more realism to the model, far more than can be hoped for from a completely enclosed structure such as a single city.

Another addition I would like to make regards external feedback to emergent behaviour. Blessed with sentience, humans have the ability to recognise new trends or behaviours that arise within a society – and this may feed back in a way which modifies their behaviour. Consider the emergence of social norms within a society. These can take the forms of fashion, social trends, and even moral structures. The latter dictates to the society as a whole what is good and what is bad (to take the extreme, consider the almost universal agreement that to kill another human is immoral). These arise from the individual beliefs of the agents. However, because they are aware of the universal level of belief, they have the ability to modify their own beliefs accordingly. This cycle produces staggering affects in social dynamics – and would have particular effect on the subject of narcissism. Narcissistic agents are very aware of their self-image, because it is their fundamental means of seizing attention from other individuals. If they took into account the dictates of right and wrong from the society, they would, for example, limit their behaviour when agents they admire are present. Ironically, their true 'false'-self would likely emerge clandestinely, thus adding another layer to their dual nature.

More and more layers of complexity could be added to the model (e.g. considering poverty as a cause of narcissism, including atomic group actions, or the introduction of power sources such as leaders); each leading one step closer to true realism. Though each step has an even greater associated complexity, if we design simulations accurately, we can hope to divine knowledge on the (uniquely human) sociality of our world. Knowledge of our past and present, our dreams and existence, of the winds of change in our societies ... and essentially ourselves.

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