An Approach to Modelling Long-Term Growth Trends in Software Systems

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Introduction

- Software **evolution** is process of continual **fixing**, **adaptation**, **enhancement** to **maintain stakeholder satisfaction**
  - in response to **changes** in **domains**, needs, **expectations**
  - intrinsic to ***E*-type,** that is real world**,** applications
  - co-evolving domains, ***many*** concurrent **activities** *at many* levels
  - **subsumes maintenance,** which is said to absorb 60 - 80% of total costs over lifecycle

- **Dependence** on computers and **demands** on professional **resources** make **planning** and **management** of evolution **vital**

- **Rate** of evolution **critical** for business

- **Long-term viewpoint** contributes to **sustainable evolution**

- Not generally addressed in current **models** and **tools** for **effort estimation**

- In particular, there is **need** for empirical **models** of evolution phenomenon

Modelling **approaches**

Modelling Approaches

- **Many approaches** to modelling
  - **Visualisation,** including **plotting**
  - **Statistical representation** and **analysis**
  - General **simulation**
  - **System dynamics models** and **simulation**
  - **Analytic modelling - from first principles**
- List is **sequence** of techniques applied to study of **software evolution**

Presentation focuses on **work in progress**

Laws of Software Evolution as Background

- Studies in late 60s and 70s led to recognition of evolution **phenomenon**

- Plotting and visualisation led to identification of **behavioural commonalties** across systems - e.g. **laws of software evolution**

- Termed ***laws*** because they relate to **mechanisms** largely **independent** of **technology** and process **detail**
  - recently discussed in FEAST and in **publications** since 1974
  - provide framework for tools and management **guidelines** - paper to appear in Annals of Softw. Eng, v. 11

- FEAST assessed their **empirical support**
  - seven **supported** after minor modification
  - see FEAST **publications**

- As stated, laws are **qualitative** **descriptors** of **behaviour**

Framework for **behavioural** **process modelling**

Laws and their support

No.	Brief Name	Law	Support
I 1974	Continuing Change	An *E*-type systems must be continually adapted else it becomes progressively less satisfactory in use	yes
II 1974	Increasing Complexity	As an *E*-type system is evolved its complexity increases unless work is done to maintain or reduce it	indirect
III 1974	Self Regulation	Global *E*-type system evolution processes are self-regulating	yes
IV 1978	Conservation of Organisational Stability	Average activity rate in an *E*-type process tends to remain constant over system lifetime or segments of that lifetime	yes
V 1978	Conservation of Familiarity	In general, the average incremental growth (growth rate trend) of *E*-type systems tends to decline	yes
VI 1991	Continuing Growth	The functional capability of *E*-type systems must be continually enhanced to maintain user satisfaction over the system lifetime	yes
VII 1996	Declining Quality	Unless rigorously adapted to take into account changes in the operational environment, the quality of an *E*-type systems will appear to decline as it is evolved	theory
VIII 1996	Feedback System (Recognised 1971, formulated 1996)	*E*-type evolution processes are multi-level, multi-loop, multi-agent feedback systems	white box models

Evolving Complexity

- **Operational domains** undergo continual change and some **assumptions** reflected in software may no longer be valid - **principle of software uncertainty**
- Software maintenance as maintenance of **validity of assumption set**
- As system is evolved, **ageing effects accumulate** unless **counteracted**
- One of these is **increasing complexity** - stated as second law of software evolution
- Unless adequately **counteracted** - by for example, **anti-regressive** work - increasing complexity will increase effort required for evolution, ultimately to **stagnation**
- **Effort** needed to achieve evolution is related to system **size**, **complexity** however **defined**
- **Reference** to complexity of the system "***as a whole***"
- **Complexity** seen as **ratio** of **effort applied** and resultant **size increment** - where size is surrogate for **functional power**

Analytic extension

Basic Formulation

- Previous observations suggest complexity is defined as:

$$C = dE/dS$$

where S = Size

E = Cumulative Effort

C = Complexity

- Also C may increase with size of total system, hence:

$$dC/dS = f(C)$$

where f(C) is a non-decreasing function

$$0 <= f(C) <= A\ C^{\beta}$$

$$0 <= \beta < 1$$

where A and β are constant parameters

Basic Formulation

- Assuming that f(C) **-->**A C $^{\beta}$, it follows that:

$$C \sim S^k$$

$$S \sim E^{1/g}$$

where $k = (1 - \beta)^{-1}$

$g = 1 + k$

$k >= 1 \quad g >= 2$

- where interpretations of g and k are linked to metrics used

- Provides basis for **models of long-term growth** based on **size/effort relationship**

e.g., **Size(t) ~ [Cumulative_effort(t)] $^{1/g}$**

What measures of size and effort?

System Size Indicators

- Size:
  - lines of code (loc), function points (fp), not widely available from historical records
  - numbers of elements - such as modules, sub-systems - **likely** to be correlated to functional power and posses a level of functional integrity

- For a system of with **n elements**, maximum number of element **interconnections** is ***n(n-1)/2***

- Reflected by: $C \sim S^2$ and $S \sim E^{1/3}$ - k = 2, g = 3

- Linked to **inverse square model** [Turski 1996]:

$$S_i = S_{i-1} + e/(S_{i-1})^2$$

Effort Indicators

- **Direct** indicators, such as person-months, always **desirable**

- But **detailed** records **not** normally **retained**

- **Meaningful study** nevertheless **possible**

- Moreover, observations suggest that effort applied is **approximately constant** over time **intervals** or **sequence of releases**

- For time period over which this holds one may assume :

cumulative effort applied ~ system age or alternatively

~ release sequence number

- ***Work-rate*** as an **indirect** **effort indicator**
  - example: **elements handled**
  - see paper for definition
  - see also ICSM 2000 paper

Three Analytical Models

$$\text{Relative Size} = (\text{Release Sequence Number})^{1/g}$$

$$\text{Relative Size} = (\text{Relative Cumulative Work-Rate})^{1/g}$$

Inverse Square Model

Model A Normalised size as a function of the release sequence number	Model B Normalise size as a function of the normalised work-rate	Model C Normalised size as a function of the release sequence number
$\underline{S}_i / S_1 = (i)^{1/g}$ for i >= 1	$\underline{S}_i / S_1 = (H_i/H_1)^{1/g'}$ for i >= 1	$\underline{S}_i / S_1 = \underline{S}_{i-1}/S_1 + [e\,(S_1)^2/(\underline{S}_{i-1})^2]$ for i >= 2

S_i and $\underline{S}_i$ stand for actual and estimated size at release i, respectively

g, g' and e are model parameters

- Examples of what can be achieved with analytical models

Some Remarks Relating to Empirical Assessment

- Data from four **industrially evolved** systems
- Representing 70 to 90s **technology**, progressively **adapted**
- Three different **organisations** (two UK, one US)
- **Three** different **application domains**
- Size measured in in ***modules*** - i.e. element counts,
- **No** direct **effort indicators** available at time of study
- **Work-rate** measured in ***modules handled***

Data availability leads to three model candidates

Systems Included in Study

System ID (symbol used in plots)	Application Domain	Main Source Code Language	Technology of First Operational Release	Number of Major Releases in Data Set	Period of System Evolution Studied (approx. in years)
A (■)	Real Time	C	1980s	19	20
B (▲)	Real Time	C	1980s	16	20
C (?)	Operating System	S3 (*)	1970s	21	15
D (+)	Information System	COBOL	1980s	13 (**)	14

(*) proprietary language of the 70s

(**) data aggregated per year

Estimated Parameters (least squares fit)

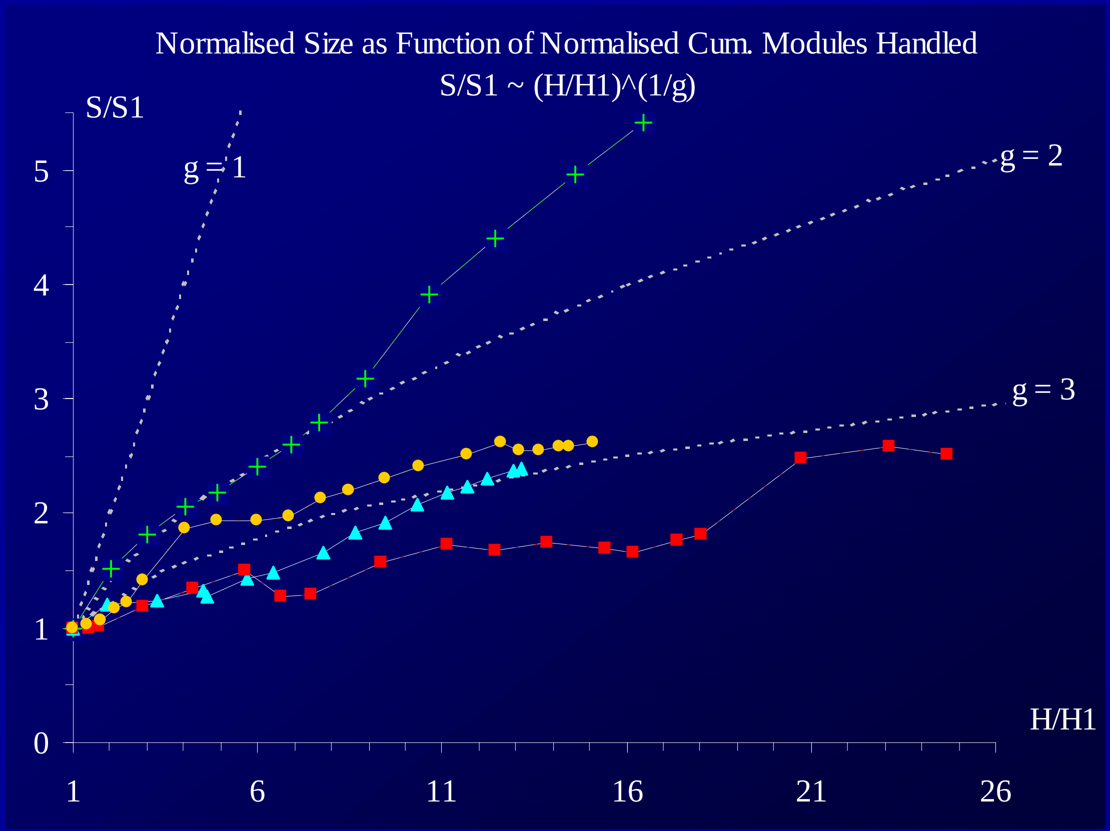
System	Model 1 Parameter g	Model 2 Parameter g’	Model 3 Parameter e
A	4.74	3.33	0.11
B	3.51	4.42	0.21
C	3.14	2.72	0.27
D (entire data set)	1.89	1.86	0.74
D (segment 1: 1 = i = 8)	2.04	2.02	0.64
D (segment 2: 9 = i = 13)	1.61 (*)	1.68 (*)	0.26 (**)

(*) without data re-normalisation (**) after data re-normalisation at i = 9

- In all systems g > 1, that is, growth at a slower rate than accumulation of effort

Growth patterns

Growth as Function of Cumulative Effort Applied



- Note closeness in 3 of the systems to "S = $E^{1/3}$ trajectory"
- One system starts following S = $E^{1/2}$ trajectory, though mid-life change requires further analysis

Modelling Precision

System	Model 1 MMRE %	Model 2 MMRE %	Model 3 MMRE %
A (*)	9.1	10.1	8.4
B (*)	11.1	8.6	9.7
C (*)	9.4	5.0	9.8
D (*)	11.7	8.4	16.8
D (segment 1: 1 <= i <= 8)	2.8	2.7	5.7
D (segment 2: 9 <= i<= 13)	5.6	2.3	1.7

(*) MMRE calculated over entire data set

- Remarkable precision for such simple models and for a process that involves human activity at all levels
- Suggests that system dynamics constraints/drive evolution
- Models likely to be useful - but see discussion of anomalies in paper

Final Remarks

- Approach provides means for **evolution planning**, **management and control**
  - tools
  - long term prognosis
  - indicator of process or organisational change

- **Extension**
  - additional measures extend models
  - measures may be obtained from historical data - e.g. developer **names** in **change log records**
  - model refinement

- **Comparison** of evolution under different paradigms
  - Object Oriented, Open Source, COTS and component intensive processes

- Input to development of **theory of software evolution**

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