FAST: a Transducer Based Language for Manipulating Trees

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Motivation

Trees are common input/output data structures

– XML query, type-checking, etc…

– Compilers/optimizers (from parse tree to parse tree)

– Tree manipulating programs: data structures algorithms, ontologies, etc…

HTML Sanitization

Removing **malicious** active code from HTML documents is a **tree transformation**

What do we Need?

Remove bad elements (scripts…)

Remove malicious URLs

Replace deprecated tags

We want to **write** these single transformations **separately** to avoid errors

Interesting Properties

Composition:
$T(x) = T_2(T_1(x))$

To achieve **speed**

Type-checking:
given two languages I,O
T(I) is always in O

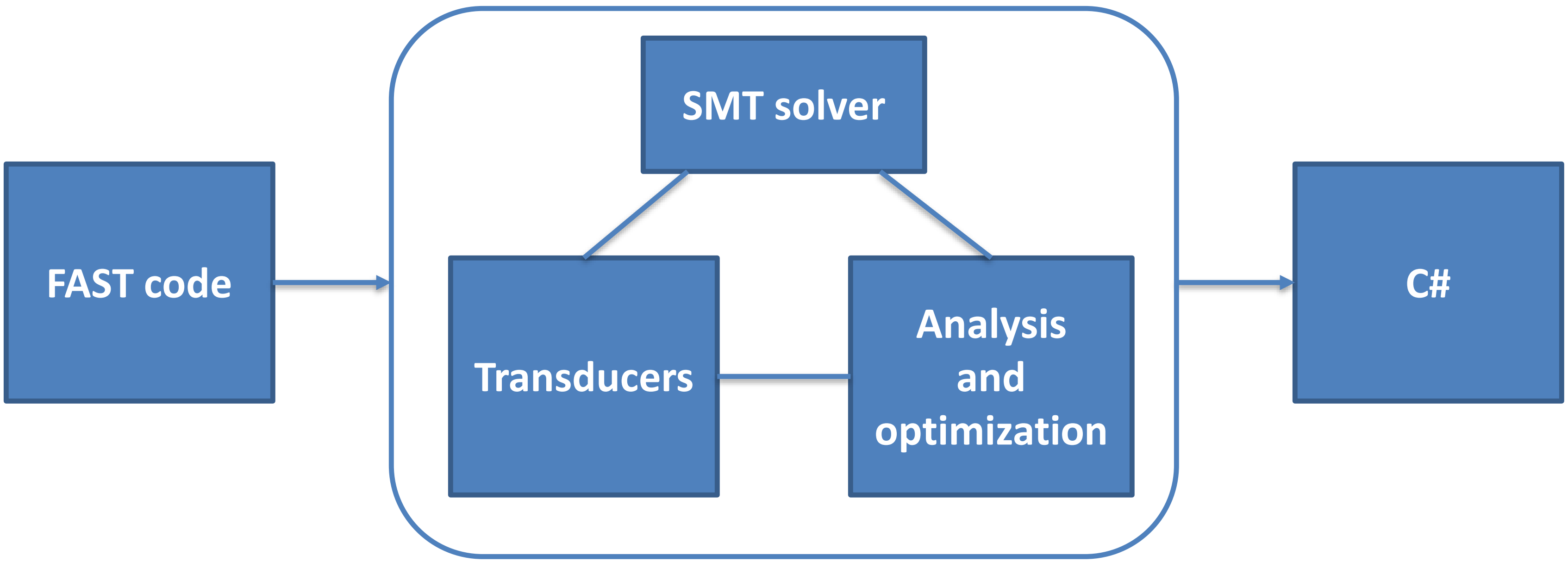
Check if the sanitizer ever produces a malicious output

Pre-image: compute the input that produces a particular output

Produce **counterexamples** if type-checking fails

DEMO: http://rise4fun.com/Fast/jN

FAST Compiler



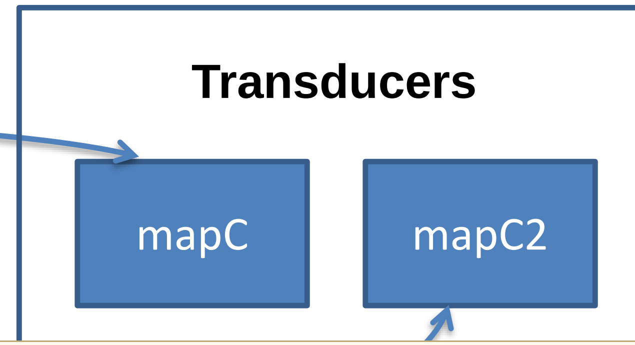
Stages by Example

deforestation.fast

```
fun f (i:int) : int := (mod (+ i 5) 26)

alphabet IList [i:int] {nil(0),cons(1)}

public trans mapC : IList -> IList {
     nil() to (nil [0])
   | cons(x) to (cons [(f i)] (mapC x))
}
```



deforestation.cs*

Microsoft.Fast.Tests.Deforestation.TreeIList — mapC2()

```
public IEnumerable<TreeIList> mapC2()
{
    if (this.symbol == IList.nil)
    {
        if (true)
        {
            yield return TreeIList.MakeTree(IList.nil, 0, new TreeIList[0] { });
        }
    }
    if (this.symbol == IList.cons)
    {
        if (t
        {
            IEnumerable<TreeIList> _mapC2_x1 = children[0].mapC2();
            foreach (var mapC2x1 in _mapC2_x1)
            {
                yield return TreeIList.MakeTree(IList.cons, ((5 + ((5 + (i % 26)) % 26)) % 26), new TreeIList[1] { mapC2x1 });
            }
        }
    }
    if (false) yield return null;
}
```

IList TreeIList.symbol

100 %

CHOOSING THE RIGHT FORMALISM

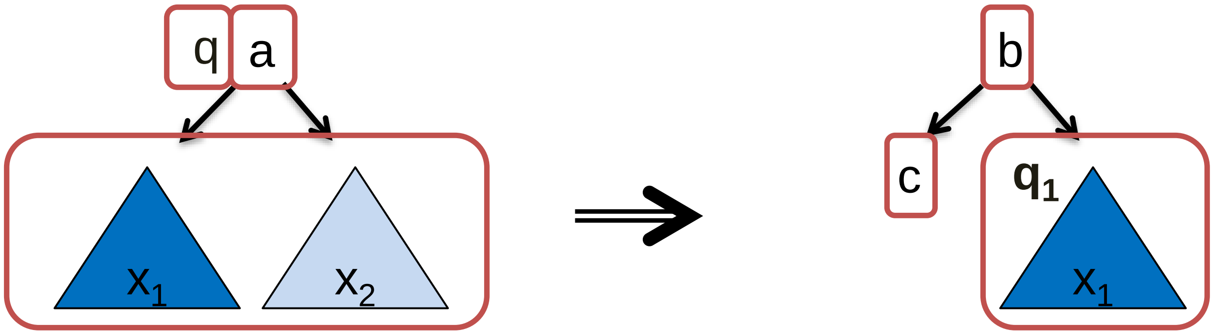
Semantics as Transducers

Goal:

find a **decidable** class
of **tree transducers**
that can **express** the previous examples

Top Down Tree Transducers [Engelfriet75]

$$q(a(x_1,x_2)) \rightarrow b(c,q_1(x_1))$$

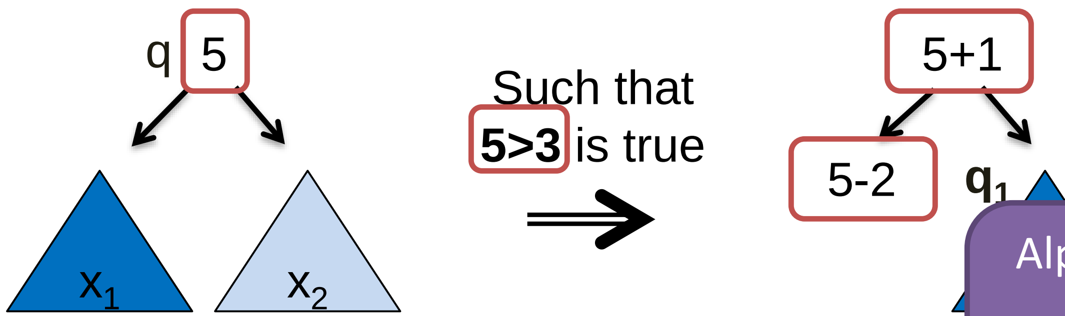


Decidable properties: type-checking, etc…

Domain expressiveness: only finite alphabets

Symbolic Tree Transducers [PSI11]

$$q(\boxed{\lambda a.a>3},(x_1,x_2)) \rightarrow \boxed{\lambda a.a+1},(\boxed{\lambda a.a-2},q_1(x_1))$$



Alphabet theory has to be **DECIDABLE**
We'll use Z3 to check predicate satisfiability

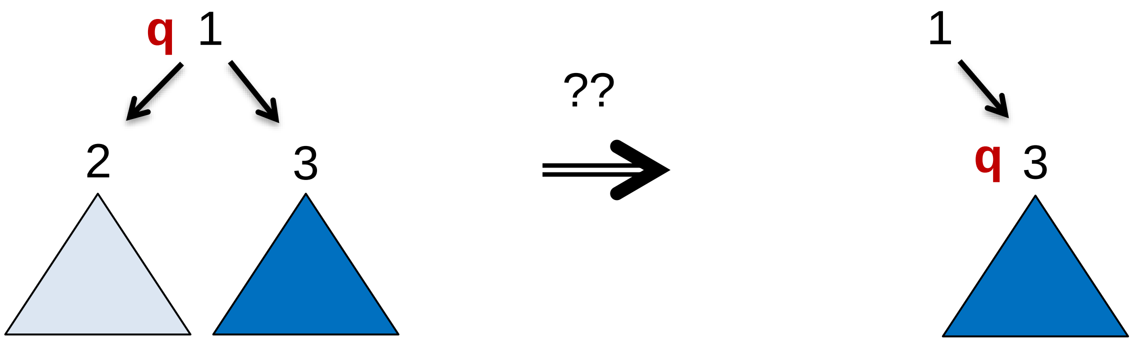
Decidable properties: type-checking, etc…

Domain expressiveness: infinite alphabets using predicates and functions

Structural expressiveness: can't delete a node without reading it first

Improving structural expressiveness

Transformation: delete the left child if its root greater than 5

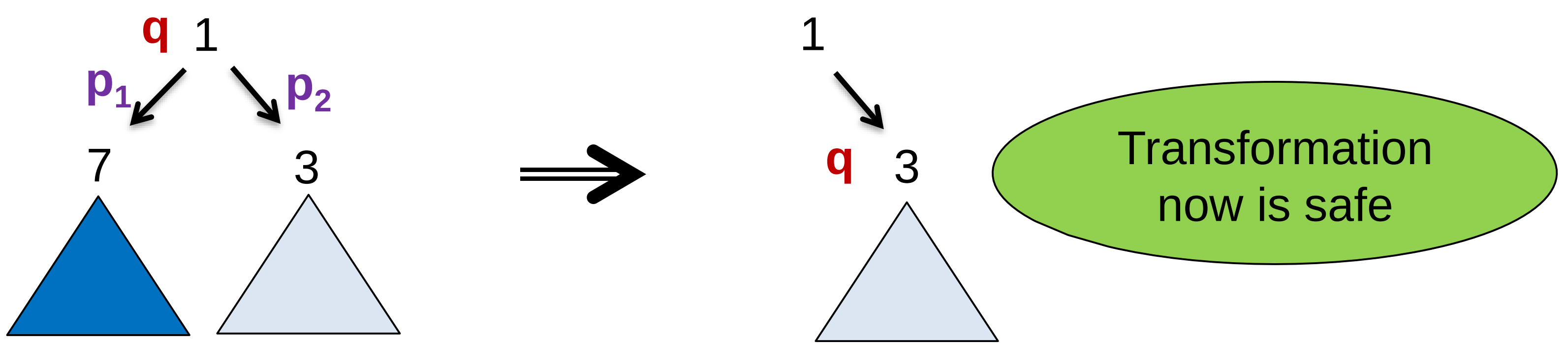


If we delete the node we **can't check** that the left child was actually greater than 5

Regular Look-Ahead (RLA)

Regular Look Ahead (TOP^R)

Transformation: delete a node if its left child is greater than 5



Rules can ask whether the children are in particular languages

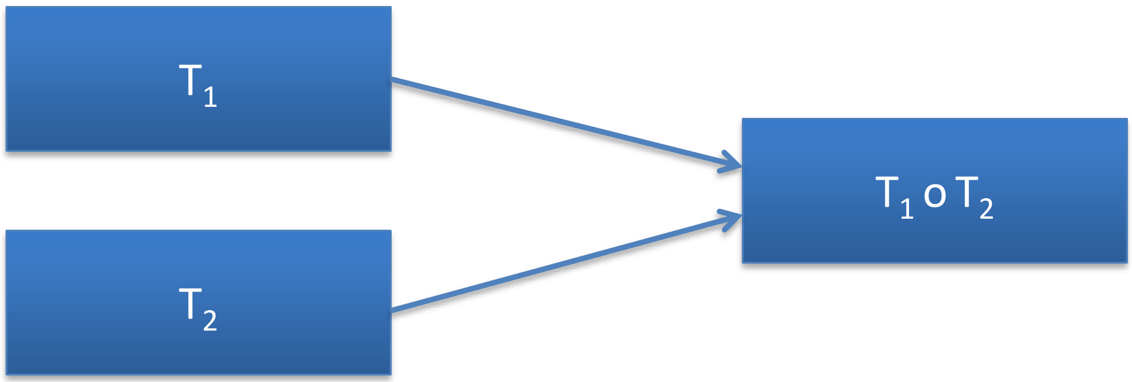
- p_1: the language of trees whose root is **greater than 5**
- p_2: the language of all trees

Decidable properties: type-checking, etc…
Domain expressiveness: infinite alphabets
Structural expressiveness: good enough to express our examples

	Decidability	Complexity	Structural Expressiveness	Infinite alphabets
Top Down Tree Transducers [Engelfriet75]	V	V	X	X
Top Down Tree Transducers with Regular Look-ahead [Engelfriet76]	V	V	~	X
Streaming Tree Transducers [AlurDantoni12]	V	X	V	X
Data Automata [Bojanczyk98]	~	X	X	V
Symbolic Tree Transducers [VeanesBjoerner11]	V	V	X	V
Symbolic Tree Transducers RLA	V	V	~	V

COMPOSITION OF SYMBOLIC TRANSDUCERS WITH REGULAR LOOKAHEAD

Composition of STT^R



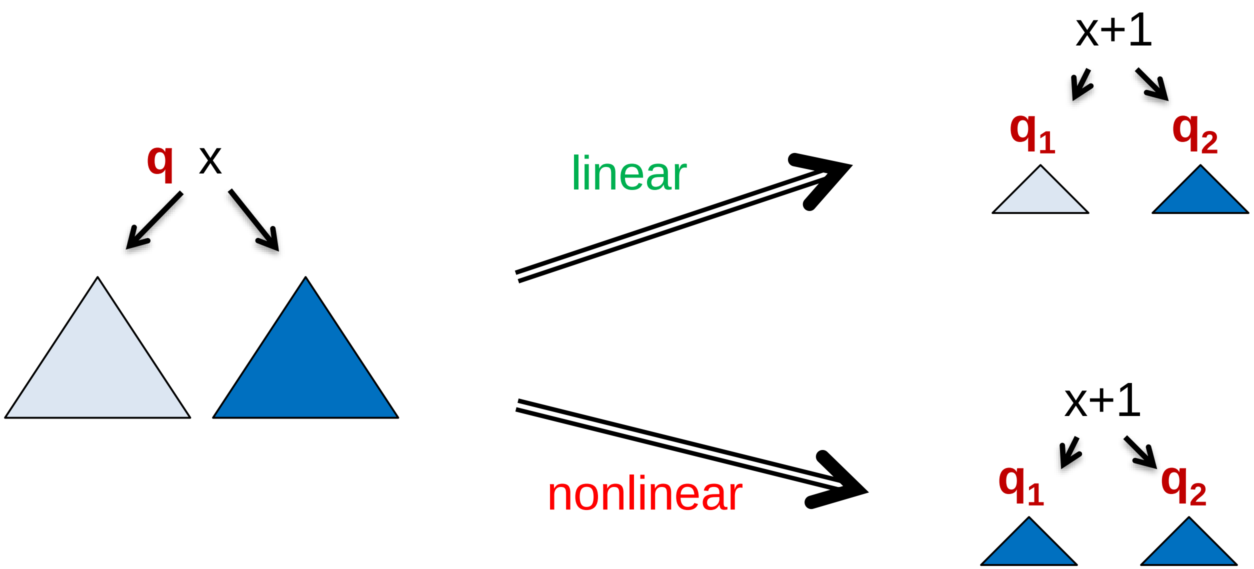
This is **not** always possible!!

Find the **biggest** class for which it is **possible**

Classes of STT^R

DETERMINISTIC: at most **one transducer rule** applies for each input tree

LINEAR: each child appear **at most once** in the right hand side of each rule



When can we Compose?

Theorem: $T(x) = T_2(T_1(x))$

definable by a Symbolic Tree Transducers with RLA if

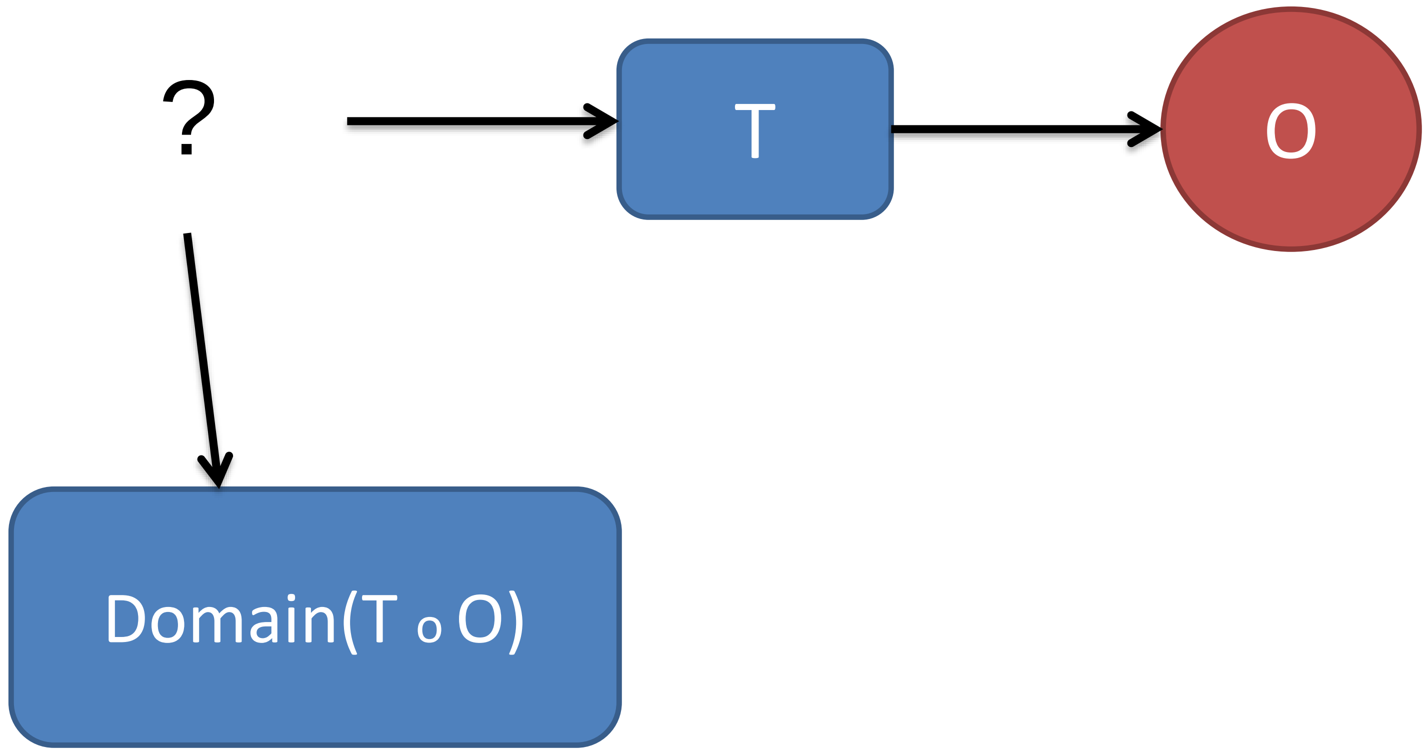
– **T_1 is deterministic, OR**

– **T_2 is linear**

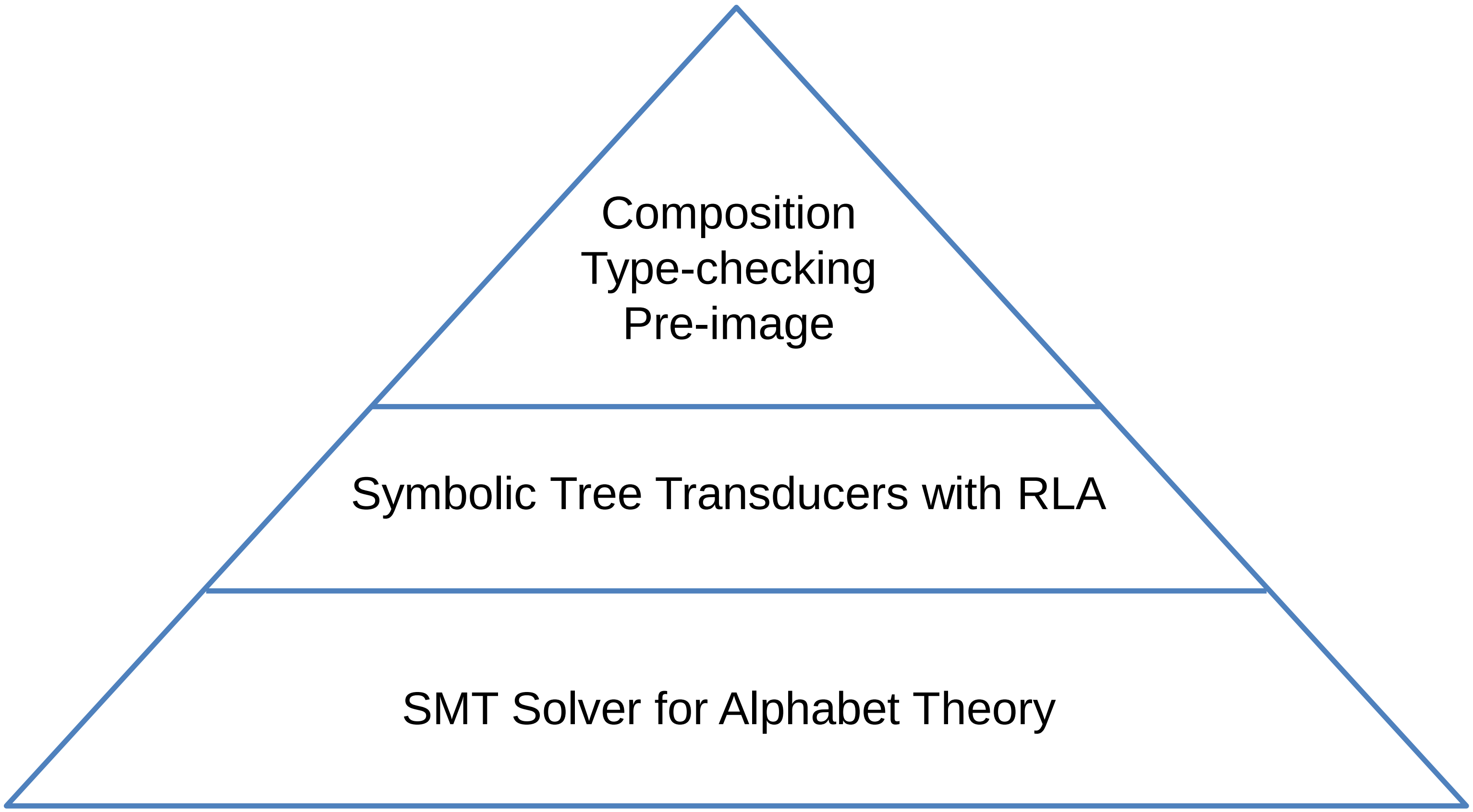
Alphabet theory has to be **DECIDABLE**
We'll use Z3 to check predicate satisfiability

All our examples fall in this category

Pre-image as Composition



FAST: Decidable by Design



CASE STUDIES AND EXPERIMENTS

Case Studies and Experiments

Program Optimization:

Deforestation of functional programs

Verification:

HTML sanitization

Analysis of functional programs

Augmented reality app store

Infinite Alphabets:
Integer
Data types

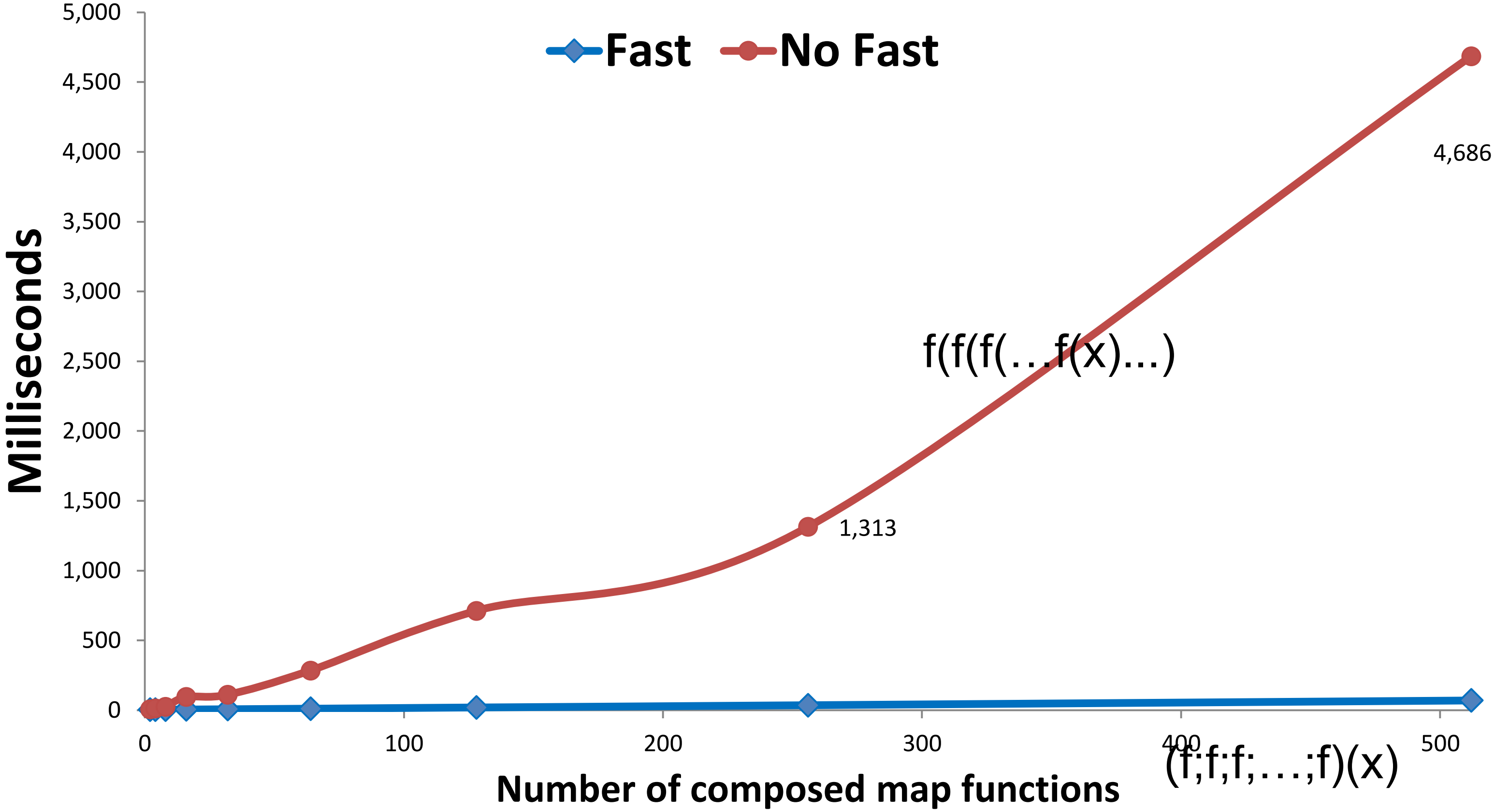
Deforestation

Removing **intermediate** data structures from programs

```
alphabet ILIst [i : int] { nil(0), cons(1) }
trans mapC: IList→ IList {
        nil()           to nil [0]
      | cons(x)         to cons [(i+5)%26] (mapC x)
}
def mapC²: IList→IList  :=  compose mapC mapC
```

ADVANTAGE: the program is a single transducer reads the input list only once, thanks to transducers **composition**

Deforestation: Speedup



Analysis of Functional Programs

```
//Increments all the elements of the list by 1
Public Trans map_inc : IntList -> IntList {
           nil() to (nil [0])
   | cons(x) to (cons [(inc i)] (map_inc x))
}
```

```
//Removes all the odd elements from the list
Public Trans filter_ev : IntList -> IntList {
           nil() to (nil [0])
   | cons(x) where (odd i) to (filter_ev x)
   | cons(x) where (even i) to (cons [i] (filter_ev x))
}
```

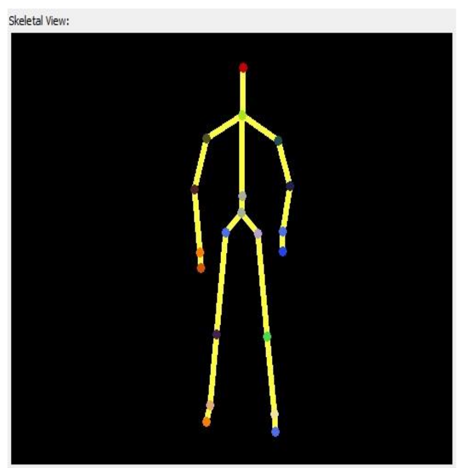
```
//Compose the four functions into a single one
Def map_filt_2 : IntList -> IntList := (compose (compose map_inc filter_ev) (compose map_inc filter_ev))
```

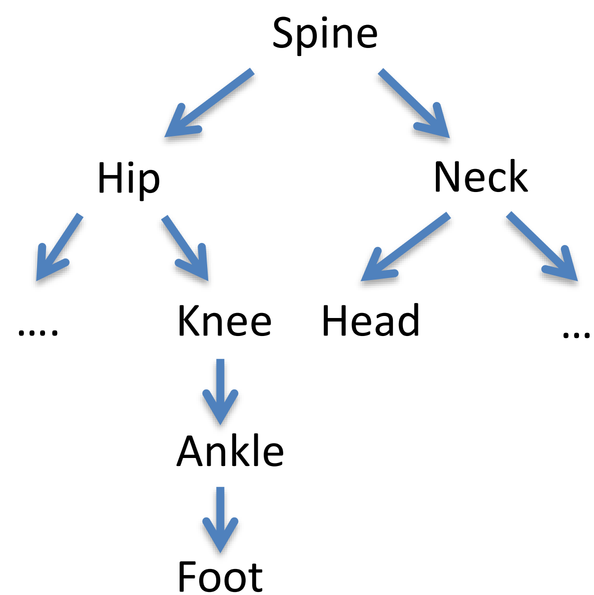
```
//Empty list languiage
Public Lang not_emp_list : IntList {
    nil()
}
//Non-Empty list languiage
Public Lang not_emp_list : IntList {
    cons(x)
}
```

```
//Check whether map_filt_2 ever outputs a non-empty list
Def map_filt_2_rest : IntList -> IntList := (restrict_out map_filt_2 not_emp_list)
AssertTrue (is_empty_trans map_filt_2_rest)
```

AR Interference Analysis

Recognizers output data that can be seen as a tree structure

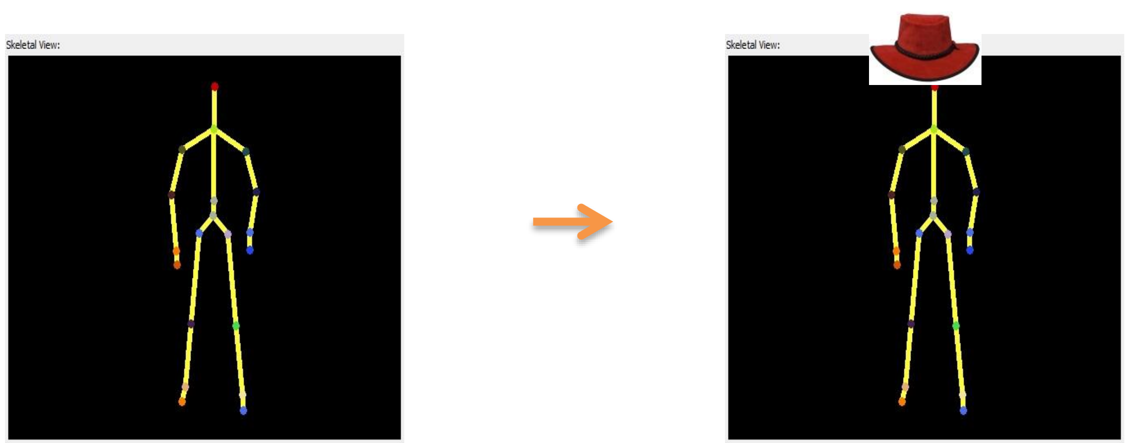




Apps as Tree Transformations

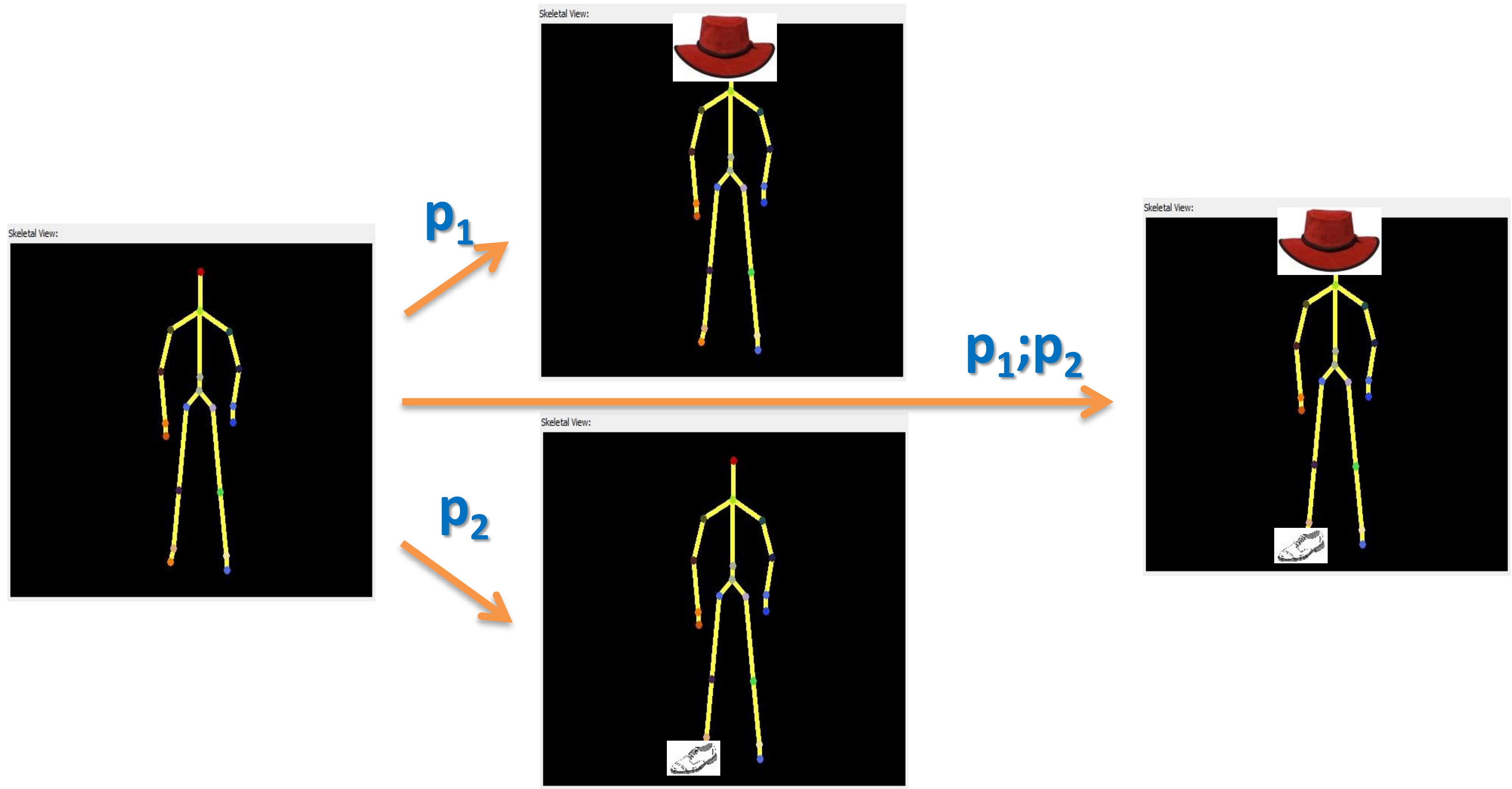
Applications that use recognizers can be modeled as **FAST** programs

```
trans addHat: STree -> STree
        Spine(x,y) to Spine(addHat(x), y)
      | Neck(h,l,r) to Neck(addHat(h), l, r)
      | Head(a) to Head(Hat(a))
```



Composition of Programs

Two **FAST** programs can be composed into a single **FAST** program



Interference analysis

Apps can be **malicious**: try to overwrite outputs of other apps

Apps **interfere** when they annotate the **same node** of a recognizer’s output

Interfering apps	
Add cat ears	Add hat
Add pin to a city	Blur a city
Amazon Buy Now button	Malicious Buy Now button

We can **compose** them and check if they interfere **statically**!!

– Put checker in the **AppStore** and analyze Apps before approval

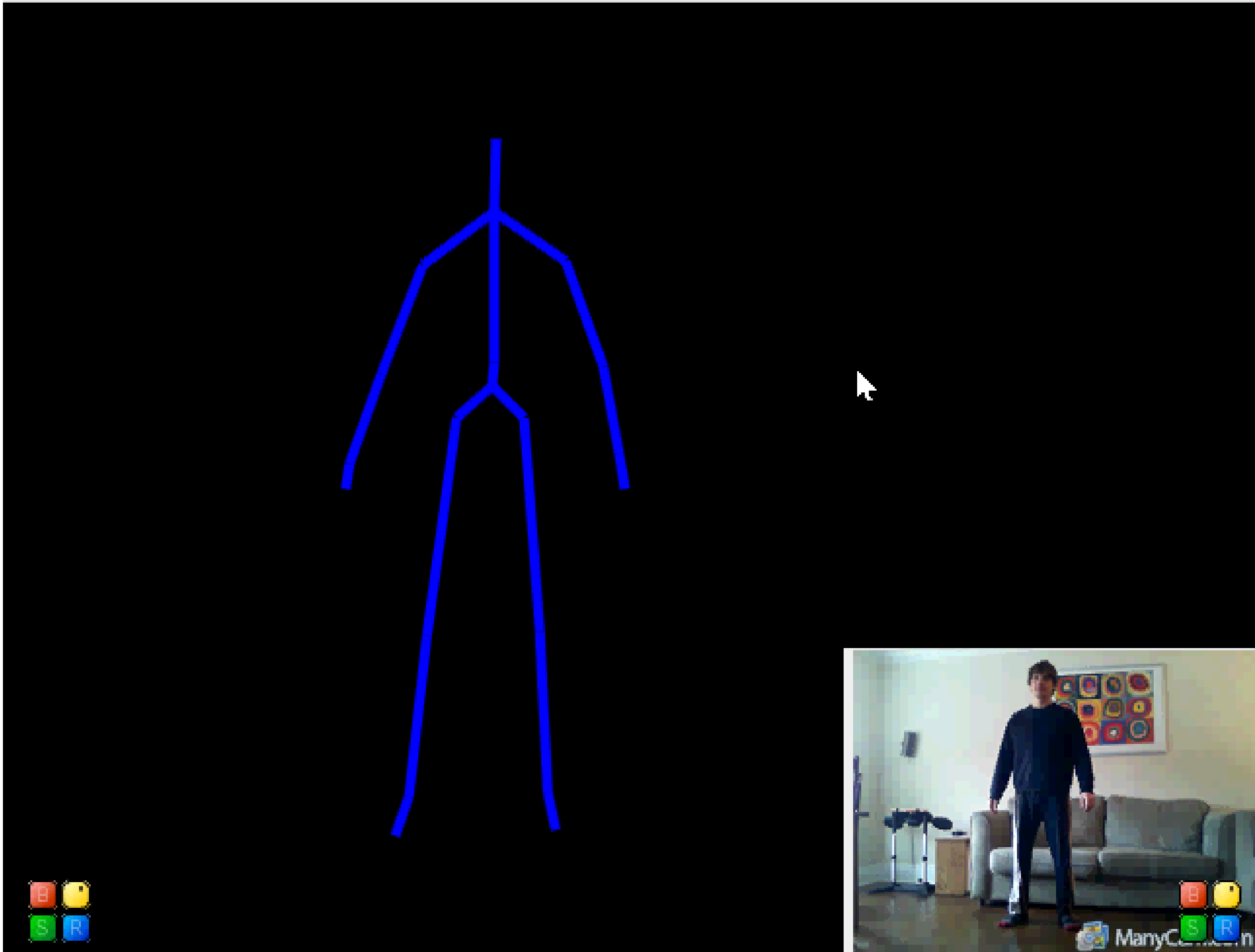
Interference Analysis in Practice

100 generated FAST programs, up to **85 functions** each

Check statically if they **conflict** pairwise for **ANY** possible input

Checked 99% of program pair in less than 0.5 sec!

For an App store these are perfectly fine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Conclusion

FAST: a versatile language for tree manipulating programs with decidable analysis

Symbolic tree transducers with RLA

FAST is online: http://rise4fun.com/Fast/