Simulation between signal machines

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joint work with Florent Becker, Tom Besson, Hadi Foroughmand and Sama Goliaei

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Laboratoire d’Informatique de l’École polytechnique

Algorithmic Questions in Dynamical Systems
March 2018 — Toulouse
1 Introduction

2 Signal Machines (Introduction and Definition)

3 Relations to Models of Computation

4 Intrinsically Universal Family of Signal Machines

5 Non-determinism (work in progress)

6 conclusion
### Outline

<table>
<thead>
<tr>
<th>One model/dynamical system</th>
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<tbody>
<tr>
<td>signal machines</td>
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<th>Relations to “usual” computational models</th>
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Outline

One model/dynamical system
- signal machines

Relations to “usual” computational models
- Turing machines
- Linear Blum, Shub and Smale model

Intrinsic universality

Non determinism
Simulation between signal machines

Introduction

Outline

One model/dynamical system

- signal machines

Relations to “usual” computational models

- Turing machines
- Linear Blum, Shub and Smale model

Intrinsic universality

- a family only

Non determinism
## Outline

### One model/dynamical system
- signal machines

### Relations to “usual” computational models
- Turing machines
- Linear Blum, Shub and Smale model

### Intrinsic universality
- a family only

### Non determinism
- same power
1. Introduction

2. Signal Machines (Introduction and Definition)

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Simulation between signal machines

Signal Machines (Introduction and Definition)

Cellular Automata: signal use

Firing Squad Synchronization (Goto, 1966)
CA: Conception with signals

Fischer (1965)

Fig. 2. Solution to the prime problem
CA: Analyzing with Signals

Das et al. (1995)

(a) Space-time diagram. (b) Filtered space-time diagram.
Signals

- Signal (meta-signal)
- Collision (rule)
Vocabulary and Example: Find the Middle

Meta-signals (speed)

- M (0)

Collision rules

- M
- M
**Vocabulary and Example: Find the Middle**

### Meta-signals (speed)

<table>
<thead>
<tr>
<th>div</th>
<th>M</th>
<th>(0)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>(3)</td>
</tr>
</tbody>
</table>

### Collision rules

- \( \text{div, } M \rightarrow \{ M, \text{hi, lo} \} \)
- \( \{ \text{lo, } M \} \rightarrow \{ \text{back, } M \} \)
- \( \{ \text{hi, back} \} \rightarrow \{ M \} \)
Vocabulary and Example: Find the Middle

Meta-signals (speed)

- $M$ (0)
- $\text{div}$ (3)
- $\text{hi}$ (1)
- $\text{lo}$ (3)

Collision rules

- $\{ \text{div, } M \} \rightarrow \{ M, \text{hi, lo} \}$
Vocabulary and Example: Find the Middle

Meta-signals (speed)

- $M$ (0)
- $\text{div}$ (3)
- $\text{hi}$ (1)
- $\text{lo}$ (3)
- $\text{back}$ (-3)

Collision rules

- $\{ \text{div, } M \} \rightarrow \{ M, \text{ hi, lo} \}$
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Vocabulary and Example: Find the Middle

Meta-signals (speed)
- $M$ (0)
- $\text{div}$ (3)
- $\text{hi}$ (1)
- $\text{lo}$ (3)
- $\text{back}$ (-3)

Collision rules
- $\{ \text{div, M} \} \rightarrow \{ M, \text{hi, lo} \}$
- $\{ \text{lo, M} \} \rightarrow \{ \text{back, M} \}$
- $\{ \text{hi, back} \} \rightarrow \{ M \}$
Simulation between signal machines

Signal Machines (Introduction and Definition)

Stack Implantation

<table>
<thead>
<tr>
<th>Name</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Add, Rem</td>
<td>1/3</td>
</tr>
<tr>
<td>A, E</td>
<td>1</td>
</tr>
<tr>
<td>U, M</td>
<td>0</td>
</tr>
<tr>
<td>$\overrightarrow{R}$</td>
<td>3</td>
</tr>
<tr>
<td>$\overleftarrow{R}$</td>
<td>$-3$</td>
</tr>
</tbody>
</table>

Collision rules

\[
\begin{align*}
\{ \text{Add, M} \} & \rightarrow \{ \text{M, A, } \overrightarrow{R} \} \\
\{ \overrightarrow{R}, \text{ M} \} & \rightarrow \{ \overrightarrow{R}, \text{ M} \} \\
\{ \text{A, } \overrightarrow{R} \} & \rightarrow \{ \text{U} \} \\
\{ \overrightarrow{R}, \text{ U} \} & \rightarrow \{ \overrightarrow{R}, \text{ U} \} \\
\{ \text{Rem, M} \} & \rightarrow \{ \text{M, E} \} \\
\{ \text{E, U} \} & \rightarrow \{ \} 
\end{align*}
\]
Stack Implantation

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</tr>
<tr>
<td>U, M</td>
<td>0</td>
</tr>
<tr>
<td>(\rightarrow R)</td>
<td>3</td>
</tr>
<tr>
<td>(\leftarrow R)</td>
<td>-3</td>
</tr>
</tbody>
</table>

Collision rules

\[ \{ \text{Add, M} \} \rightarrow \{ \text{M}, \text{A}, \rightarrow R \} \]
\[ \{ \rightarrow R, \text{M} \} \rightarrow \{ \rightarrow R, \text{M} \} \]
\[ \{ \text{A}, \rightarrow R \} \rightarrow \{ \text{U} \} \]
\[ \{ \rightarrow R, \text{U} \} \rightarrow \{ \rightarrow R, \text{U} \} \]
\[ \{ \text{Rem, M} \} \rightarrow \{ \text{M}, \text{E} \} \]
\[ \{ \text{E}, \text{U} \} \rightarrow \{ \} \]
Simulation between signal machines

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<td>A, E</td>
<td>1</td>
</tr>
<tr>
<td>U, M</td>
<td>0</td>
</tr>
<tr>
<td>→ R</td>
<td>3</td>
</tr>
<tr>
<td>← R</td>
<td>−3</td>
</tr>
</tbody>
</table>

 Collision rules

\[
\begin{align*}
\{ \text{Add, M} \} & \rightarrow \{ \text{M, A, } \rightarrow R \} \\
\{ \rightarrow R, \text{ M} \} & \rightarrow \{ \rightarrow R, \text{ M} \} \\
\{ \text{A, } \rightarrow R \} & \rightarrow \{ \text{U} \} \\
\{ \rightarrow R, \text{ U} \} & \rightarrow \{ \rightarrow R, \text{ U} \} \\
\{ \text{Rem, M} \} & \rightarrow \{ \text{M, E} \} \\
\{ \text{E, U} \} & \rightarrow \{ \} \\
\end{align*}
\]
Fractal Generation
Complex Dynamics
Complex Dynamics
Simulation between signal machines
Signal Machines (Introduction and Definition)

Complex Dynamics
1 Introduction

2 Signal Machines (Introduction and Definition)

3 Relations to Models of Computation

4 Intrinsically Universal Family of Signal Machines

5 Non-determinism (work in progress)

6 conclusion
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3. Relations to Models of Computation
   - Discrete computation: Turing Machines
   - Analog Computation: linear Blum, Shub and Smale

4. Intrinsically Universal Family of Signal Machines

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Simulation between signal machines
Relations to Models of Computation
Discrete computation: Turing Machines

Turing-computation

Turing Machine

Simulation
### Turing-computation

#### Also with restrictions
- all different speed
- only 2 → 2 rules (conservative)
- one-to-one rules (reversible)

#### Rational machines
- speeds $\in \mathbb{Q}$
- initial positions $\in \mathbb{Q}$
- $\Rightarrow$ collision coordinates $\in \mathbb{Q}$
- exact simulation on computer/TM

#### Any above and
- rational ($\mathbb{Q}$)

#### Undecidability
- finite number de collisions
- meta-signal appereance
- use of a rule
- disappearing of all signals
- involvement of a signal in any collision
- extension on the side, etc.
1 Introduction

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Computing with Real Numbers

Encoding

<table>
<thead>
<tr>
<th>base</th>
<th>val</th>
<th>Zero</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sign test

<table>
<thead>
<tr>
<th>sign?</th>
<th>pos</th>
<th>Zero</th>
<th>neg</th>
</tr>
</thead>
<tbody>
<tr>
<td>base</td>
<td>val</td>
<td></td>
<td>val</td>
</tr>
</tbody>
</table>

Addition

<table>
<thead>
<tr>
<th>base</th>
<th>val</th>
<th>base</th>
<th>val</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>1</td>
<td>side</td>
<td>side</td>
<td></td>
</tr>
<tr>
<td>down</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>side</td>
<td>down0</td>
<td>add</td>
<td></td>
</tr>
<tr>
<td>end</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>up</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Simulation between signal machines
Relations to Models of Computation
Analog Computation: linear Blum, Shub and Smale

Multiplication by a constant

By $-0.9$

By $-\frac{1}{2}$

By $\frac{2}{3}$
Simulation between signal machines
Relations to Models of Computation
Analog Computation: linear Blum, Shub and Smale

Multiplication by a constant

By $-0.9$

By $-\frac{1}{2}$

By $\frac{2}{3}$

By $\sqrt{2}$

By $\pi$

Signal speeds are constants of the machine
If $x \leq 0$ then val is meet before base

\[
\begin{align*}
\text{val} & \quad \text{base} \\
-0.9x & \quad \text{val} \quad \text{base} \\
\text{base} & \quad \text{val} \\
\frac{1}{2}x & \quad \text{base} \quad \text{val} \\
\text{base} & \quad \text{val} \\
\frac{2}{3}x & \quad \text{base} \quad \text{val} \\
\text{base} & \quad \text{val} \\
\sqrt{2}x & \quad \text{base} \quad \text{val} \\
\text{base} & \quad \text{val} \\
\pi x & \quad \text{base} \quad \text{val}
\end{align*}
\]
Simulation between signal machines

Relations to Models of Computation

Analog Computation: linear Blum, Shub and Smale

Multiplication by a constant

- By $-0.9$
  - $-0.9x$

- By $-\frac{1}{2}$
  - $\frac{1}{2}x$

- By $\frac{2}{3}$
  - $\frac{2}{3}x$

- By $\sqrt{2}$
  - $\sqrt{2}x$

- By $\pi$
  - $\pi x$

- Signal speeds are constants of the machine
- If $x \leq 0$ then val is meet before base
Simulation between signal machines
Relations to Models of Computation
Analog Computation: linear Blum, Shub and Smale

Zooming out

Finite sequence of real numbers
Simulation between signal machines

Relations to Models of Computation

Analog Computation: linear Blum, Shub and Smale

Zooming out

Finite sequence of real numbers + Dynamics

- finite state automata
- sign test
- addition, multiplication by constant
- (set constant value)
- (enlarge the array)

Like a Turing machine with real numbers on the tape
Simulation between signal machines
Relations to Models of Computation
Analog Computation: linear Blum, Shub and Smale

Linear Blum, Shub and Smale with shift

Encoding a configuration

```
-1  b  a  a  a  c  -2
```
Simulation between signal machines
Relations to Models of Computation
Analog Computation: linear Blum, Shub and Smale

Linear Blum, Shub and Smale with shift

Encoding a configuration

\[ \begin{array}{cccccccc}
-1 & -1 & b & d_1 & a & d_2 & a & d_3 & c & -3 & -2 & -2
\end{array} \]

Simulating a signal machine: loop

1. Compute the minimum time to a collision, \( \delta \)
2. Advance time by \( \delta \)
3. Update all distances
4. Process collision(s)
Simulation between signal machines
Relations to Models of Computation
Analog Computation: linear Blum, Shub and Smale

Linear Blum, Shub and Smale with shift

Encoding a configuration

-1  -1  ...  b  d_1  ...  a  d_2  ...  a  d_3  ...  c  -3  ...  -2  -2  ...
Linear Blum, Shub and Smale with shift

Encoding a configuration

Simulating a signal machine: loop

1. Compute the minimum time to a collision, $\delta$
2. Advance time by $\delta$ (update all distances)
3. Process collision(s)
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4 Intrinsically Universal Family of Signal Machines
   - Concept and Definition
   - Global Scheme
   - Macro-Collision
   - Preparation (shrink, test and check)

5 Non-determinism (work in progress)

6 conclusion
Simulation between signal machines

Intrinsically Universal Family of Signal Machines

Concept and Definition

Intrinsic Universality
Being able to simulate any other dynamical system of the its class.

Cellular Automata
- regular (Albert and Čulik II, 1987; Mazoyer and Rapaport, 1998; Ollinger, 2001)
- reversible (Durand-Lose, 1997)
- freezing [Theyssier et Al.]

Tile Assembly Systems
- possible at $T=2$ and above (Woods, 2013)
- impossible at $T=1$ (Meunier et al., 2014)
Simulation for Signal Machines

Space-Time Diagram Mimicking

$m_1$, $m_2$, $m_3$, $m_4$

Signal Machine Simulation

$U_S$ simulates $A$ if there is function from the configurations of $A$ to the ones of $U_S$ s.t. the space-time issued from the image always mimics the original one.
Theorem

- For any finite set of real numbers $S$, there is a signal machine $U_S$, that can simulate any machine whose speeds belong to $S$.
- The set of $U_S$ where $S$ ranges over finite sets of real numbers is an intrinsically universal family of signal machines.

Rest of this section

Let $S$ be any finite set of real numbers, let $A$ be any signal machine whose speeds belongs to $S$, $U_S$ is progressively constructed as simulation is presented.
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Macro-Signal

- Meta-signal of $\mathcal{A}$ identified with numbers
- Unary encoding of numbers

**Structure**

$i \mu^\sigma$: $\sigma$th signal, $i$th speed

Diagram showing the structure with labels for $i$, $\mu$, $\sigma$, and supporting zones.
Global scheme

When Support Zones Meet

1. provide a delay
2. test if macro-collision is appropriate and what macro-signals are involved
3. if OK
   - start the macro-collision

Hypotheses for macro-collision

- no other macro-signal nor macro-collision will interfere
- speed of involved macro-signals ranged $[j, \ldots, i]$ (included)
- their main signals intersect at a unique point
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5. Non-determinism (work in progress)

6. conclusion
Removing Unused Tables and Sending ids to Table
Collision Rules Encoding

One rule after the other

Encoding of \( \{ 3\mu^1, 7\mu^4, 8\mu^5 \} \rightarrow \{ 2\mu^3, 4\mu^1 \} \) in the direction \( i \).
Comparison of id’s in the if-part of a Rule
Rule Selection
Generating the Output
Whole resolution
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Simulation between signal machines
Intrinsically Universal Family of Signal Machines
Preparation (shrink, test and check)

**Good Cases**

**Bad Case**
Simulation between signal machines
Intrinsically Universal Family of Signal Machines
Preparation (shrink, test and check)

Shrinking Unit

\[ \begin{align*}
    a_0 &\quad b_0 \\
    a_1 &\quad b_1 \\
    a_2 &\quad b_2 \\
    a_3 &
\end{align*} \]
Simulation between signal machines
Intrinsically Universal Family of Signal Machines
Preparation (shrink, test and check)

Shrink
Simulation between signal machines

Intrinsically Universal Family of Signal Machines

Preparation (shrink, test and check)

Testing for Other main $\emptyset$ Signals

\[
\begin{align*}
(s_i + (\varepsilon - 2)s_{\text{max}}) & \quad \text{test-left-ok}_i \\
(0, 0) & \quad \text{test-left-up}_i \\
(1.5\varepsilon s_i, 1.5\varepsilon) & \quad \text{test-right-up}_i \\
\text{test-right}_i & \quad \text{test-right-ok}_i \\
\text{check-up}_i & \quad \text{check-right}_i \\
\text{main } i_{\text{ok-test}} & \quad \text{main } i_{\text{test-right-ok}} \\
\end{align*}
\]
Simulation between signal machines
Intrinsically Universal Family of Signal Machines
Preparation (shrink, test and check)

Checking the right positioning of Other main $\emptyset$ Signals
Detecting Potential Overlaps
Whole Preparation
Simulation between signal machines
Intrinsically Universal Family of Signal Machines
Preparation (shrink, test and check)

Exact 3-signal collision
Simulation between signal machines

Intrinsically Universal Family of Signal Machines

Preparation (shrink, test and check)

Some examples
Some examples
Some examples
Some examples
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4. Intrinsically Universal Family of Signal Machines

5. Non-determinism (work in progress)
   - Definition and example
     - Strategy
     - Implantation

6. conclusion
Non-determinism in rule output

Meta-signals

<table>
<thead>
<tr>
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<th>Value</th>
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<tbody>
<tr>
<td>a</td>
<td>0</td>
</tr>
<tr>
<td>b</td>
<td>-1</td>
</tr>
<tr>
<td>c</td>
<td>1</td>
</tr>
</tbody>
</table>

Collision rules

- \{ a, b \} → \{ a, c \}
- \{ a, b \} → \{ b \}
- \{ c, a \} → \{ b \}
- \{ c, a \} → \{ a \}
Non-determinism in rule output

Meta-signals
- a : 0
- b : -1
- c : 1

Collision rules
- \{a, b\} → \{a, c\}
- \{a, b\} → \{b\}
- \{c, a\} → \{b\}
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Non-determinism in rule output

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Collision rules

{ a, b } → { a, c }
{ a, b } → { b }
{ c, a } → { b }
{ c, a } → { a }

Shifted superposition

collision possible
Non-determinism in rule output

Meta-signals
- $a$: 0
- $b$: -1
- $c$: 1

Collision rules
- $\{a, b\} \rightarrow \{a, c\}$
- $\{a, b\} \rightarrow \{b\}$
- $\{c, a\} \rightarrow \{b\}$
- $\{c, a\} \rightarrow \{a\}$

Shifted superposition
- no collision possible
Simulation between signal machines
Non-determinism (work in progress)
Definition and example

Non-determinism in rule output

Meta-signals
a 0
b -1
c 1

Collision rules
{ a, b } → { a, c }
{ a, b } → { b }
{ c, a } → { b }
{ c, a } → { a }

Shifted superposition
Non-determinism in rule output

Meta-signals
\[
\begin{align*}
a &= 0 \\
b &= -1 \\
c &= 1 \\
\end{align*}
\]

Collision rules
\[
\begin{align*}
\{ a, b \} &\rightarrow \{ a, c \} \\
\{ a, b \} &\rightarrow \{ b \} \\
\{ c, a \} &\rightarrow \{ b \} \\
\{ c, a \} &\rightarrow \{ a \} \\
\end{align*}
\]

Shifted superposition

no collision possible
Introduction

Signal Machines (Introduction and Definition)

Relations to Models of Computation

Intrinsically Universal Family of Signal Machines

Non-determinism (work in progress)
  - Definition and example
  - Strategy
  - Implantation

Conclusion
Simulation between signal machines
Non-determinism (work in progress)

Strategy

All possible universes
\[ \mathcal{U} = \left\{ \begin{array}{l}
\end{array} \right\} \]

Unbounded signals

Information held:
\[ \left\{ (v_\alpha, u_\alpha) \right\}_\alpha \]
such that:
\[ v_\alpha \in \{ \emptyset, a, b, c \} \]
\[ \biguplus_\alpha u_\alpha = \mathcal{U} \]
All possible universes

\[ \mathcal{U} = \{ \text{All diagrams} \} \]

Unbounded signals

Information held:

\[ \{(v_\alpha, u_\alpha)\}_\alpha \]

such that:

\[ v_\alpha \in \{\emptyset, a, b, c\} \]

\[ \biguplus_\alpha u_\alpha = \mathcal{U} \]
Simulation between signal machines
Non-determinism (work in progress)
Strategy

All possible universes
\[ \mathcal{U} = \{ \text{[diagram]} \} \]

Unbounded signals
Information held:
\[ \{ (v_\alpha, u_\alpha) \}_\alpha \]
such that:
\[ v_\alpha \in \{ \emptyset, a, b, c \} \]
\[ \biguplus_\alpha u_\alpha = \mathcal{U} \]

Future unknown
Simulation between signal machines
Non-determinism (work in progress)
Strategy

All possible universes

\[ \mathcal{U} = \left\{ \begin{array}{c}
\text{ } \\
\text{ } \\
\text{ } \\
\text{ } \\
\text{ } \\
\end{array} \right\} \]

Unbounded signals

Information held:

\[ \left\{ (\nu_\alpha, \mu_\alpha) \right\}_\alpha \]

such that:

\[ \nu_\alpha \in \{ \emptyset, a, b, c \} \]

\[ \biguplus_\alpha \mu_\alpha = \mathcal{U} \]

Future unknown

{ (c, { }) } 
{ (\emptyset, { { } } ) }
All possible universes

\[ \mathcal{U} = \left\{ \begin{array}{c}
\emptyset, \mathbb{A}, \mathbb{B}, \mathbb{C}
\end{array} \right\} \]

Unbounded signals

Information held:

\[ \{(v_\alpha, u_\alpha)\}_\alpha \]

such that:

\[ v_\alpha \in \{\emptyset, a, b, c\} \]

\[ \biguplus_\alpha u_\alpha = \mathcal{U} \]

Future unknown

Distinguish
All possible universes

\[ \mathcal{U} = \{ \text{universes} \} \]

Unbounded signals

Information held:

\[ \{ (v_\alpha, u_\alpha) \}_{\alpha} \]

such that:

\[ v_\alpha \in \{ \emptyset, a, b, c \} \]

\[ \bigcup_{\alpha} u_\alpha = \mathcal{U} \]

Future unknown

Distinguish

\[ \{ (c.1, \{ 1 \}) \} \]

\[ \{ (c.3, \{ 3 \}) \} \]
Simulation between signal machines
Non-determinism (work in progress)
Strategy

All possible universes

\[ U = \left\{ \begin{array}{c}
\end{array} \right\} \]

Unbounded signals

Information held:

\[ \{(v_{\alpha}, u_{\alpha})\}_{\alpha} \]

such that:

\[ v_{\alpha} \in \{\emptyset, a, b, c\} \]

\[ \biguplus_{\alpha} u_{\alpha} = U \]

Future unknown

Distinguish
1 Introduction

2 Signal Machines (Introduction and Definition)

3 Relations to Models of Computation

4 Intrinsically Universal Family of Signal Machines

5 Non-determinism (work in progress)
   - Definition and example
   - Strategy
   - Implantation

6 conclusion
Macro-collision

\[ \{ (v_\alpha, u_\alpha) \}_\alpha \text{ meets } \left\{ (v'_\beta, u'_\beta) \right\}_\beta \]

1. \[ E_1 = \left\{ \left( (v_\alpha, v'_\beta), u_\alpha \land u'_\beta \right) \right\}_{\alpha, \beta} \]
2. \[ E_2 = \left\{ ((v, v'), u \land u') \in E_1 \mid u \land u' \neq \emptyset \right\} \]
3. \[ E_3 = \left\{ (\emptyset, w) \mid ((\emptyset, \emptyset), w) \in E_2 \}
\quad \cup \left\{ (\{\mu\}, w) \mid (\{\mu\}, \emptyset), w) \in E_2 \lor ((\emptyset, \mu), w) \in E_2 \}
\quad \cup \left\{ (\rho^+.\mu, \rho(\mu, \nu) \land w) \mid ((\mu, \nu), w) \in E_2 \land \rho^- = \{\mu, \nu\} \right\} \]

4. \[ \text{Out Speed} = \left\{ \text{Speed}(\mu) \mid \exists \mu, (F, w) \in E_3, \mu \in F \right\} \]
5. \[ \forall s \in \text{out}, \]
\[ \text{Out}_s = \left\{ (\mu, w) \mid \exists F, (F, w) \in E_3 \land \mu \in F, \text{Speed}(\mu) = s \right\} \]
\[ \cup \left\{ (\emptyset, w) \mid \exists F, (F, w) \in E_3 \land \forall \mu \in F, \text{Speed}(\mu) \neq s \right\} \]

- Compatible string encodings
Displaying the operations
Displaying the operations
1 Introduction

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5 Non-determinism (work in progress)

6 conclusion
Very rich setting

Intrinsically universal family of signal machines

Non-deterministic signal machine are not “more powerful”
• Very rich setting

• Intrinsically universal family of signal machines
  • What is the complexity?

• Non-deterministic signal machine are not “more powerful”
  • How to extract “result”? 
  • What is the complexity?
Very rich setting

Intrinsically universal family of signal machines
What is the complexity?

Non-deterministic signal machine are not “more powerful”
How to extract “result”?  
What is the complexity?

Augmented signal machines
That’s all folks!
Thank you for your attention


