Cells are plausible targets for high-level spatial languages

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Spatial Computing Workshop
@ IEEE SASO 2008
Compiling “band-detect”

Proto

```lisp
(def band-detector (signal lo hi)
  (and (> signal lo)
       (< signal hi)))

(let ((v (diffuse (aTc) 0.8 0.05)))
  (green (band-detect v 0.2 1)))
```

Weiss bacteria
Outline

• Background:
  – Programming bacteria
  – Proto
• Compilation
• Optimization
HLLs & Bacteria

• High-level languages:
  – Shorter programs mean less efficient code
  – Optimizing compilers can help

• Bacteria
  – Extremely tight resource constraints
  – Inherently parallel chemical execution
Synthetic Biology Vision
"Can I have this network of parts?"

"Here's a set of parts, 1-N, that implement your network"

"Can I have three inverters?"

"Here's a set of PDP inverters, 1→N, that each send and receive via a fungible signal carrier, PoPS."

"I need a few DNA binding proteins."

"Here's a set of DNA binding proteins, 1→N, that each recognize a unique cognate DNA site, choose any."

"Get me this DNA."

"Here's your DNA."

Spatial Computer

TAATCGACTCACTATAGGGAGA
Band detect: behavior

Proto

Weiss bacteria
Band detect: code

(def band-detector (signal lo hi)
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       (< signal hi)))

(let
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  (green (band-detect v 0.2 1)))

simpler, more reusable
BioBrick Primitives

- Regulatory Site
- Ribosome Binding Site
- Terminator
- Protein Coding Sequence
- Signalling Compound Part

\[ X \text{ represses transcription} \]
\[ X \text{ induces transcription} \]
\[ \text{Transcription produces } X \]

\[ X + Y \rightarrow Z \text{ } X \text{ and } Y \text{ react, forming } Z \]

Typical functional unit:
Proto: a light-weight spatial computing language

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Proto: a light-weight spatial computing language

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Proto to GRNs: First Steps

- Logical: **AND, OR, NOT** ✓
- Flow control: **IF, MUX** ✓
- Arithmetic: +, −, *, /, log, exp, ...
- Relational: >, <, =

Two possible implementations:
- Regulation
- Reaction
Digital Arithmetic is Expensive

- 1 operation
- 5 operations/bit

Use digital for booleans, analog for numbers
Arithmetic

- \( c \): constitutive expression
- \((+ \ A \ B)\): same chemical represents both
- \((-\ A \ B)\): \(A+B\rightarrow C\)
- \((\log A), (\exp A)\): lookup tables
  - approximate w. summary of > tests?
- \((* \ A \ B), (/ \ A \ B)\): log add, subtract

Range? How many bits?
Relational: $A \rightarrow D$ conversion

- $A + B \rightarrow C$
  - $(< A \: B)$
  - $(> A \: B)$
  - $(= A \: B)$
  - $(\neq A \: B)$
Naïve Implementation
## Resources Required

<table>
<thead>
<tr>
<th>Resource</th>
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<th>Naive</th>
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<tbody>
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<td>11</td>
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<tr>
<td>Protein coding sequence</td>
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<td>14</td>
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<td>14</td>
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<tr>
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Optimize: Constant Elimination

$\text{aTc} \rightarrow A$

$A \rightarrow B C$

$B + D \rightarrow Y$

$C + E \rightarrow X$

$B \rightarrow D F$

$E \rightarrow G$

$F \rightarrow H G H$

$H \rightarrow J$

$J \rightarrow \text{out GFP}$

$G \rightarrow H$

$H \rightarrow J$

$J \rightarrow \text{out GFP}$
Optimize: Algebraic Simp. (1/2)
Optimize: Algebraic Simp. (2/2)
Optimize: Dead Code Elimination
Optimize: Copy Propagation
Optimize: Use-Definition Analysis
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Contributions

- Sketch of HLL to BioBrick compilation
  - Example: Weiss band-detect
- Mixed analog/digital computation
- Optimization can be effective!

But will it work...?