Living with Concurrency

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Bob Dewar & Ed Schonberg

Computer Science Education: Where Are the Software Engineers of Tomorrow?

http://www.stsc.hill.af.mil/CrossTalk/2008/01/0801DewarSchonberg.html

- Mathematics requirements in CS programs are shrinking.
- The development of programming skills in several languages is giving way to cookbook approaches using large libraries and special-purpose packages.
- The resulting set of skills is insufficient for today's software industry. . .

They quote. . .

Bjarne Stroustrup

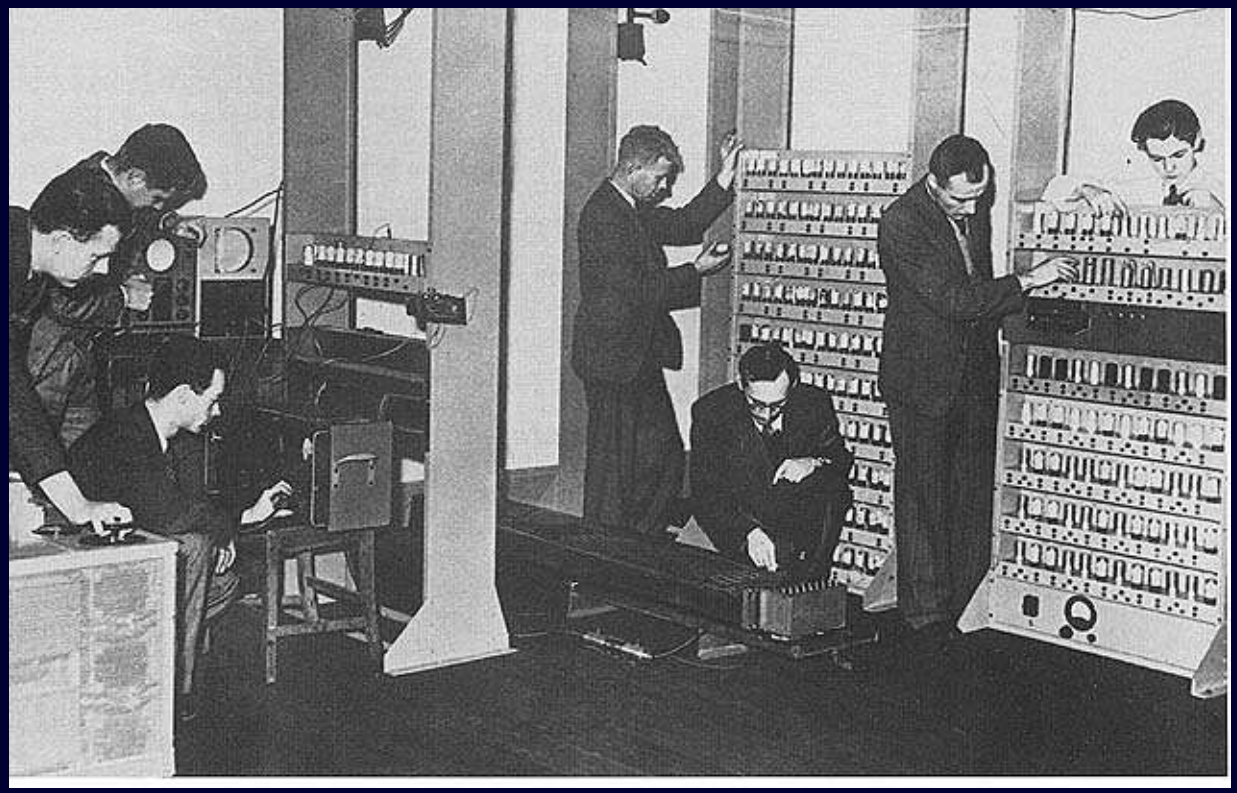
"I have had a lot of complaints about [the use of Java as a first programming language] from industry, specifically from AT&T, IBM, Intel, Bloomberg, NI, Microsoft, Lockheed-Martin, and more.

"[Texas A&M] did [teach Java as the first language]. Then I started teaching C++ to the electrical engineers and when the EE students started to out-program the CS students, the CS department switched to C++."

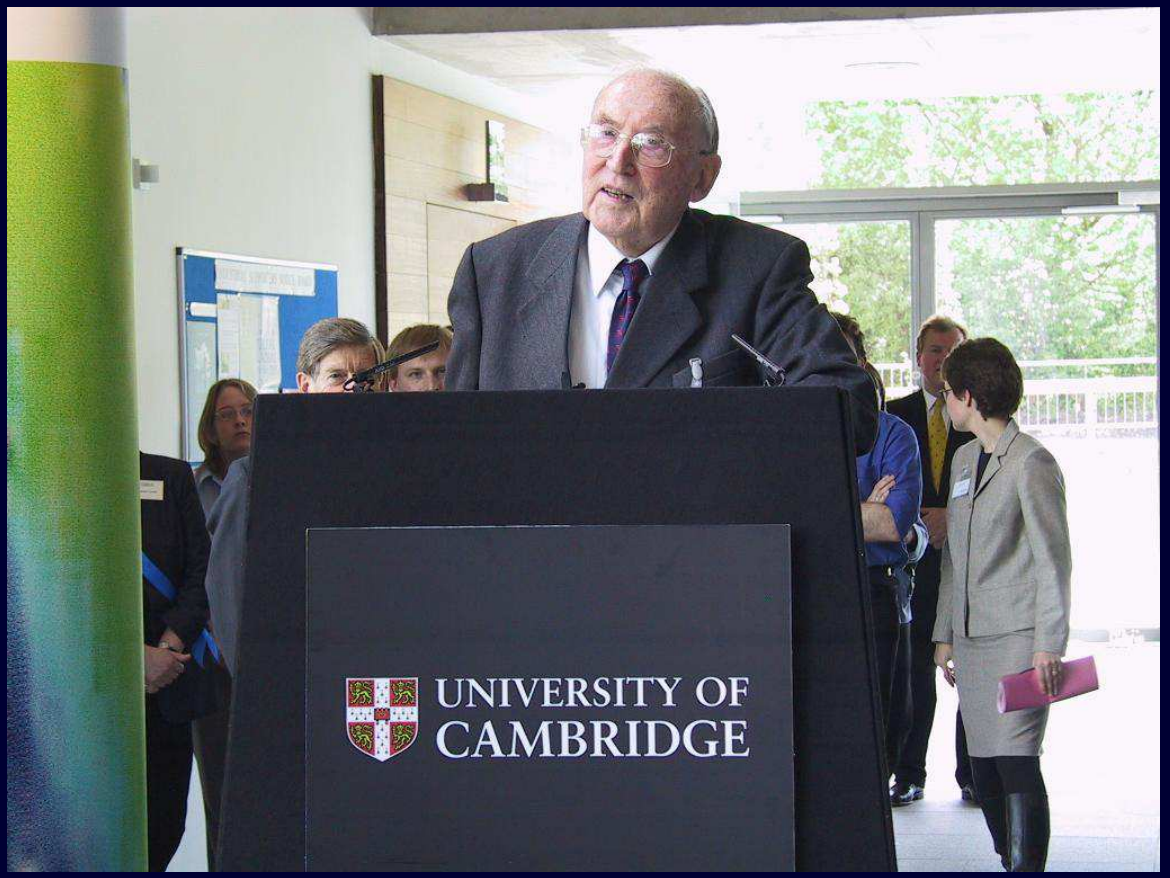
At [XYZU], our [assembler and C++] students acquire and refine analytical and communications skills that make them better able to approach any problem creatively and successfully; the study habits and work ethic they develop are those needed for success in demanding graduate and professional programs and in real-world careers.

EDSAC II

Maurice Wilkes



Maurice Wilkes



Maurice Wilkes

"As soon as we started programming, we found to our surprise that it wasn't as easy to get programs right as we had thought.

"Debugging had to be discovered.

"I can remember the exact instant when I realized that a large part of my life from then on was going to be spent in finding mistakes in my own programs."

Java as the first language. . .

- The good news is that students learn to
  - program without distractions
  - use libraries, packages, . . .
  - enjoy programming (pretty results)

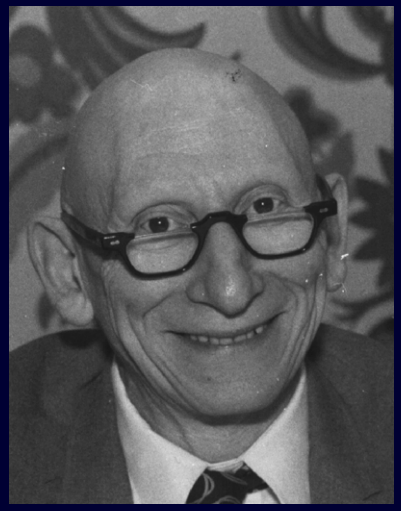
- The bad news is that students
  - don't use algorithms
  - are scared of pointers
  - don't appreciate costs

"A cynic is a man who knows the price of everything but the value of nothing."

Oscar Wilde (1854-1900)

"A LISP programmer knows the value of everything, but the cost of nothing."

Alan Perlis (1922-1990)



```
default (Integer,Rational,Float)
infixr 9 #
series f = f : repeat 0
instance Num a => Num [a] where
   fromInteger c = series(fromInteger c)
   negate (f:ft) = -f : -ft
   (f:ft) + (g:gt) = f+g : ft+gt
   (f:ft) * gs@(g:gt) = f*g : ft*gs + series(f)*gt
instance Fractional a => Fractional [a] where
   (f:ft) / (g:gt) = qs where qs = f/g : series(1/g)*(ft-qs*gt)
(f:ft) # gs@(0:gt) = f : gt*(ft#gs)
revert (0:ft) = rs where rs = 0 : 1/(ft#rs)
integral fs = 0 : zipWith (/) fs [1..]
derivative (_:ft) = zipWith (*) ft [1..]
```

(Doug McIlroy, 1998)

$$\frac{dy}{dx} = y \qquad y(0) = 1$$

$$y = 1 + \int_0^x y(t)\,dt$$

```
expx = 1 + (integral expx)
```

```
[ 1/1, 1/1, 1/2, 1/6, 1/6, 1/24, 1/720, ... ]
```

$$\frac{d}{dx}\sin x = \cos x \qquad \sin 0 = 0$$

$$\frac{d}{dx}\cos x = -\sin x \qquad \cos 0 = 1$$

```
sinx = integral cosx
```

```
cosx = 1 - (integral sinx)
```

```
[ 1/1, -1/6, 1/120, -1/5040, ... ]
```

```
[ 1/1, -1/2, 1/24, -1/720, ... ]
```

"I would like to see components become a dignified branch of software engineering."

(Doug McIlroy, 1968)

Language is not the issue!

You should be able to think with:

- objects

  C#, C++, Eiffel, Java, Smalltalk, . . .

- functions

  LISP, Scheme, ML, Haskell, . . .

- data

  lists, trees, graphs, maps, . . . , and corresponding algorithms

- hardware

  registers, caches, addresses, pointers, . . .

- concurrency

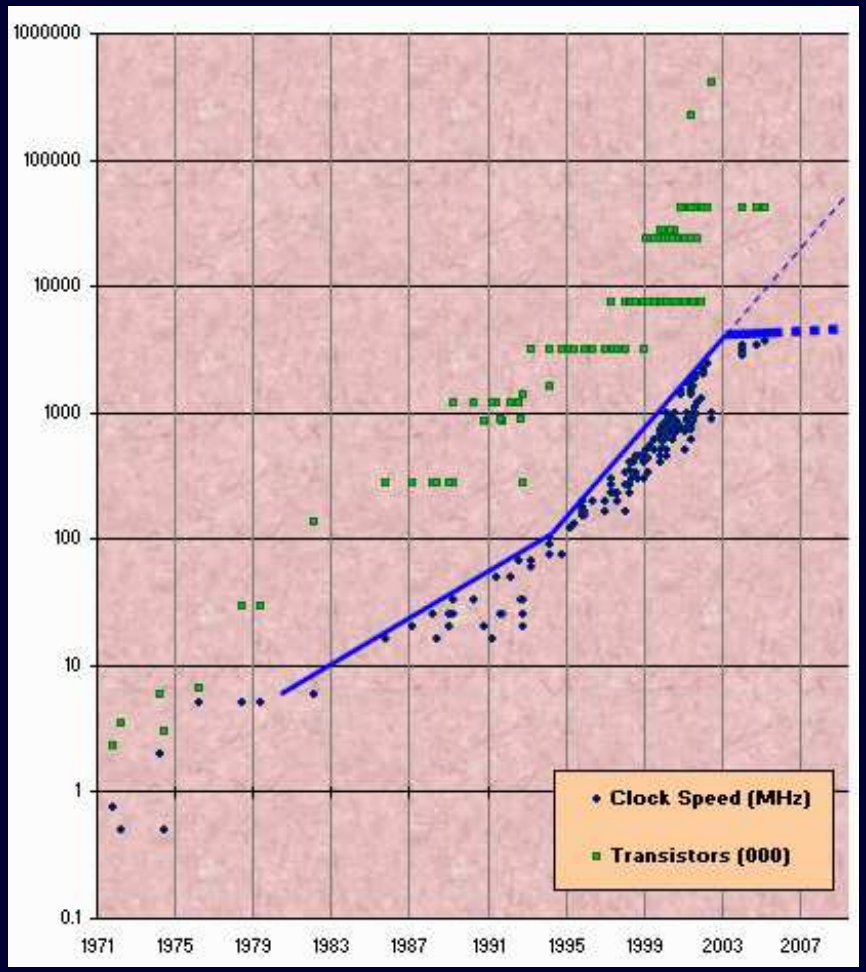
  processes, threads, semaphores, monitors, . . .

You have to know lots of other things too, of course,. . .

- "soft" skills
- project management
- collaborative work
- software development processes
- applications
- . . .

Why Concurrency?

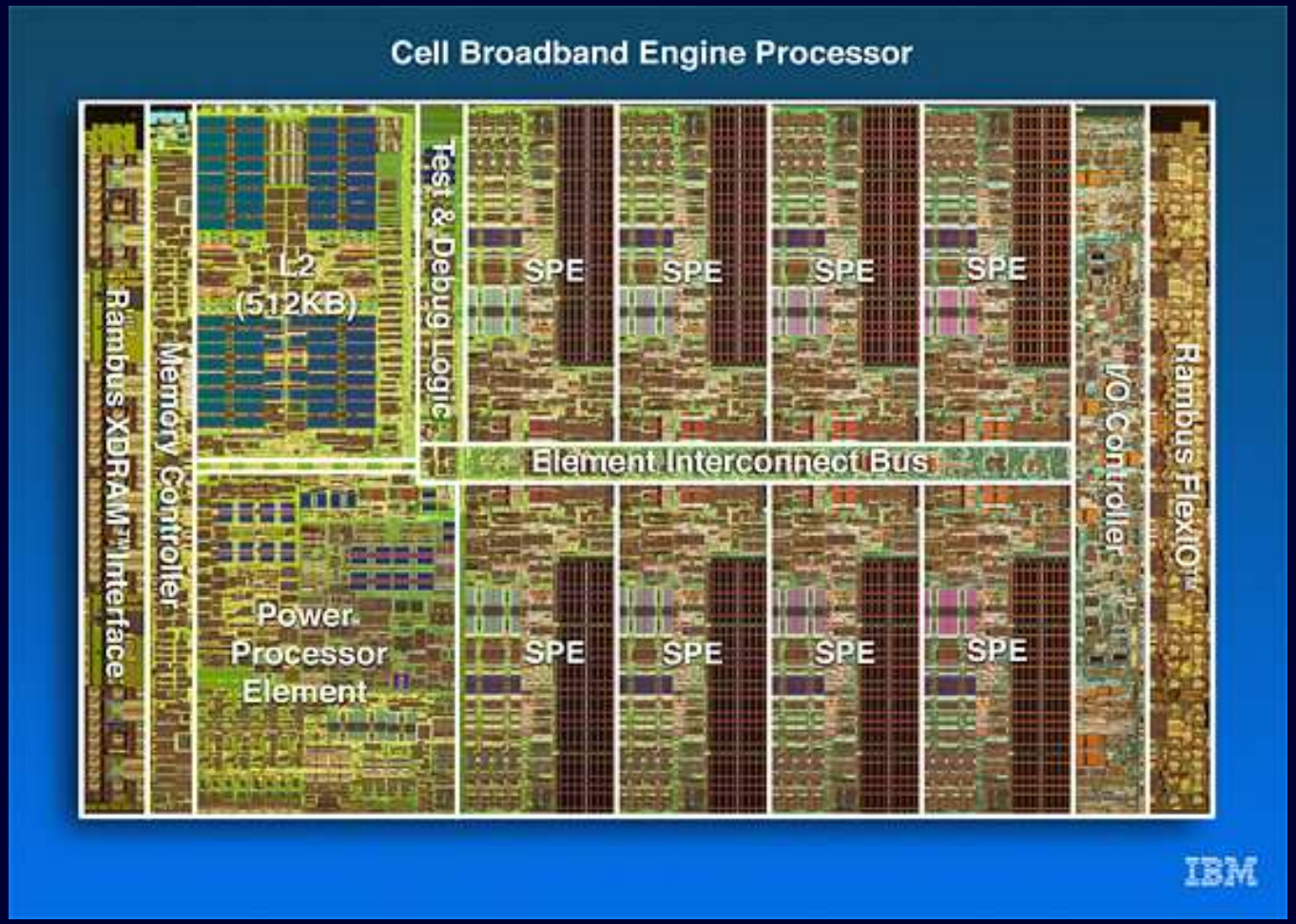
Why Concurrency?



[Dr. Dobbs Journal, 3/2005]

Why Concurrency?

Why Concurrency?



SPE = SIMD Synergistic Processor Element

Problem:

Concurrent programming is hard !

deadlock, livelock, starvation, race conditions, mamihlapinatapai, . . .


Presentation
Business Logic
Data

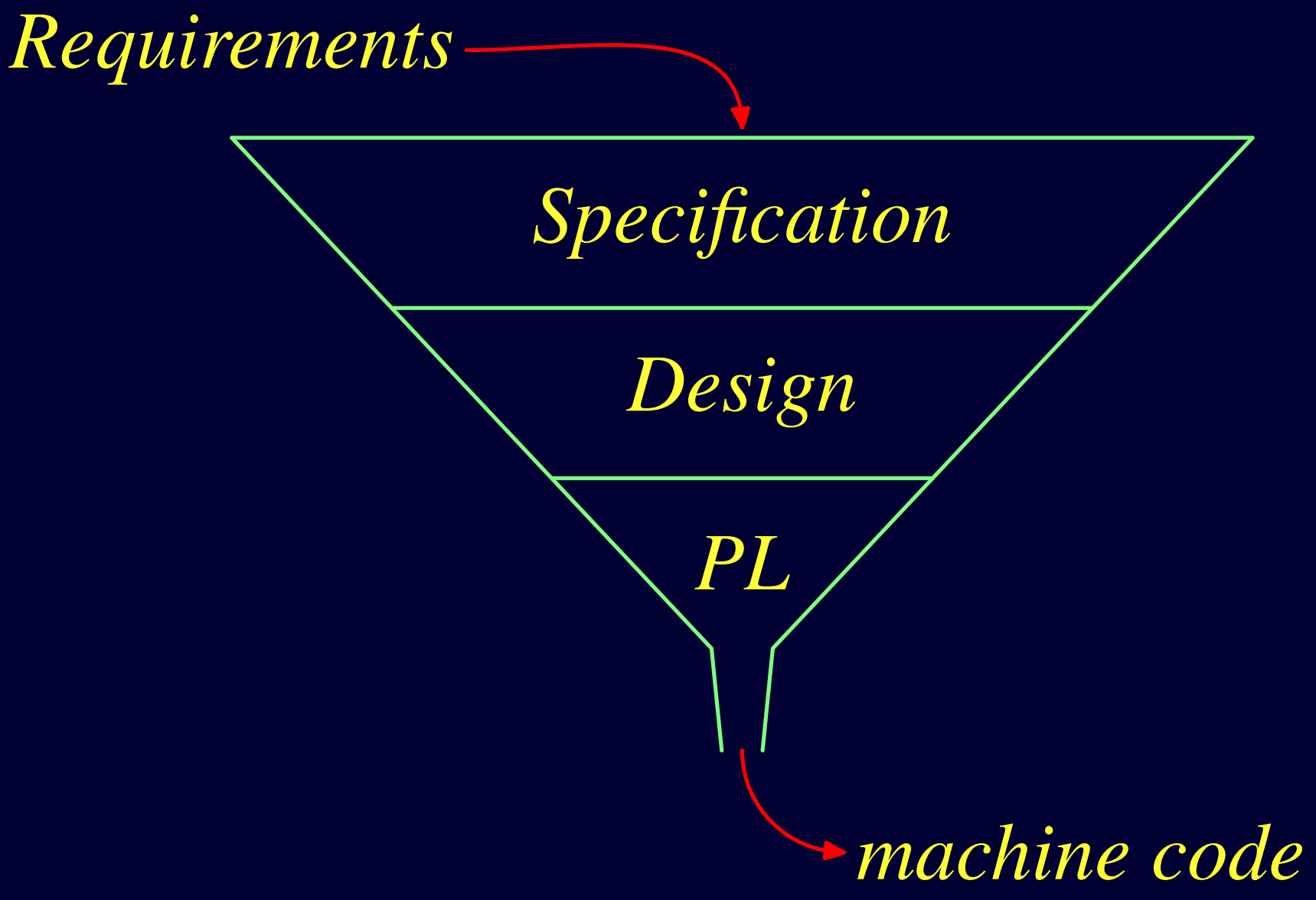

Presentation
Business Logic
Data
⇐ concurrency

The development of business applications using OO middleware has reached unparalleled complexity. In spite of greatly improved tools and development practices, more and more of the IT budget is wasted in maintenance rather than adding business value.

Dave Thomas (2008)

We must and can build concurrent computation models that are far more deterministic, and we must judiciously and carefully introduce nondeterminism where needed. Nondeterminism should be explicitly added to programs, and only where needed, as it is in sequential programming. Threads take the opposite approach. They make programs absurdly nondeterministic and rely on programming style to constrain that nondeterminism to achieve deterministic aims.

Edward Lee (2006)


Requirements
Specification
Design
PL
machine code

Change moves upwards in the funnel:

spaghetti $\xrightarrow{??}$ waterfall

structured code $\longrightarrow$ SADT
Structured Analysis & Design Technique

object-oriented languages $\longrightarrow$ OOAD
Object-Oriented Analysis & Design

aspect-oriented languages $\longrightarrow$ AOSD
Aspect-Oriented Software Development

Therefore:

To effect change in the

software development process,

we must change the

programming paradigm.

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Aspect-Oriented Software Development

process-oriented languages $\xrightarrow{??}$ POMDD
Process-Oriented Model-Driven Design

Hypothesis

POMDD will succeed because:

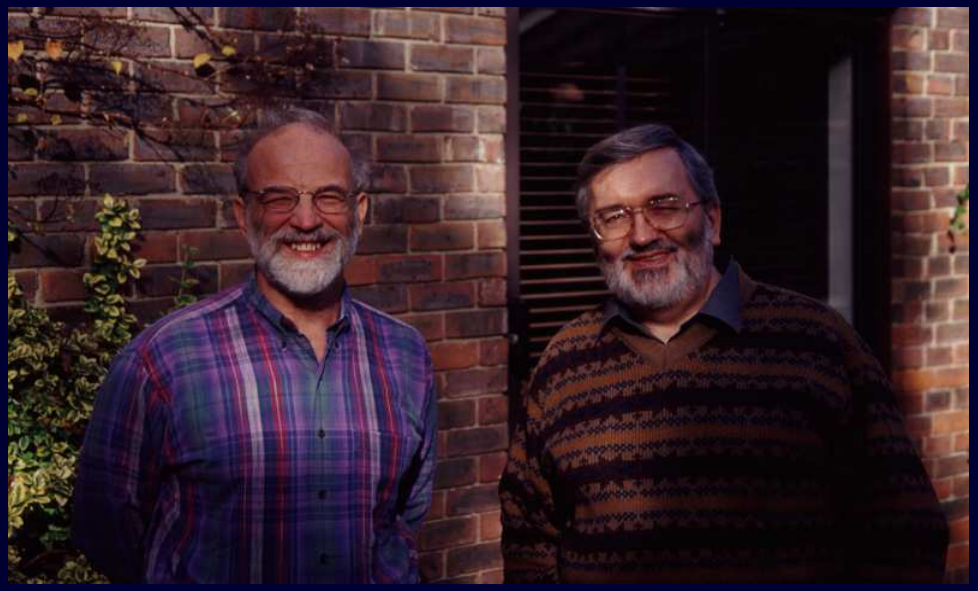
- real world $\cong$ concurrent processes
- concurrent processes $\Rightarrow$ multiprocessors
- multiprocessors $\Rightarrow$ concurrent software
- concurrent software $\Rightarrow$ models real world

- cells/processes $\Rightarrow$ lower coupling
- lower coupling $\Rightarrow$ refactoring
- experience (1970s) $\Rightarrow$ we can do it !

The Erasmus Project

Desiderius Erasmus of Rotterdam (1466-1536)

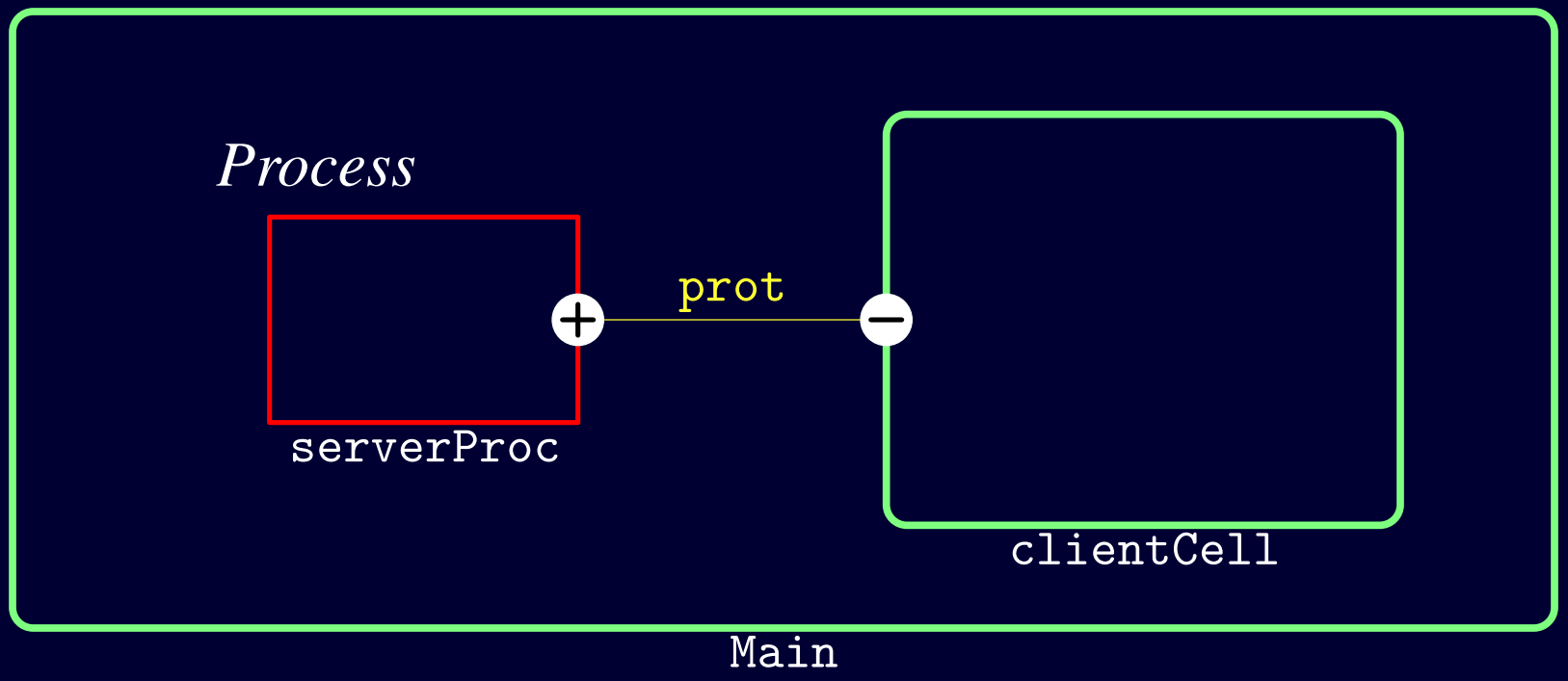
The Erasmus Project



Cell


```
Main = ();

Main();
```




```
prot = [ ];
serverProc = { p +: prot | };
clientCell = ( p -: prot | );
Main = ( p :: prot; serverProc(p); clientCell(p) );

Main();
```

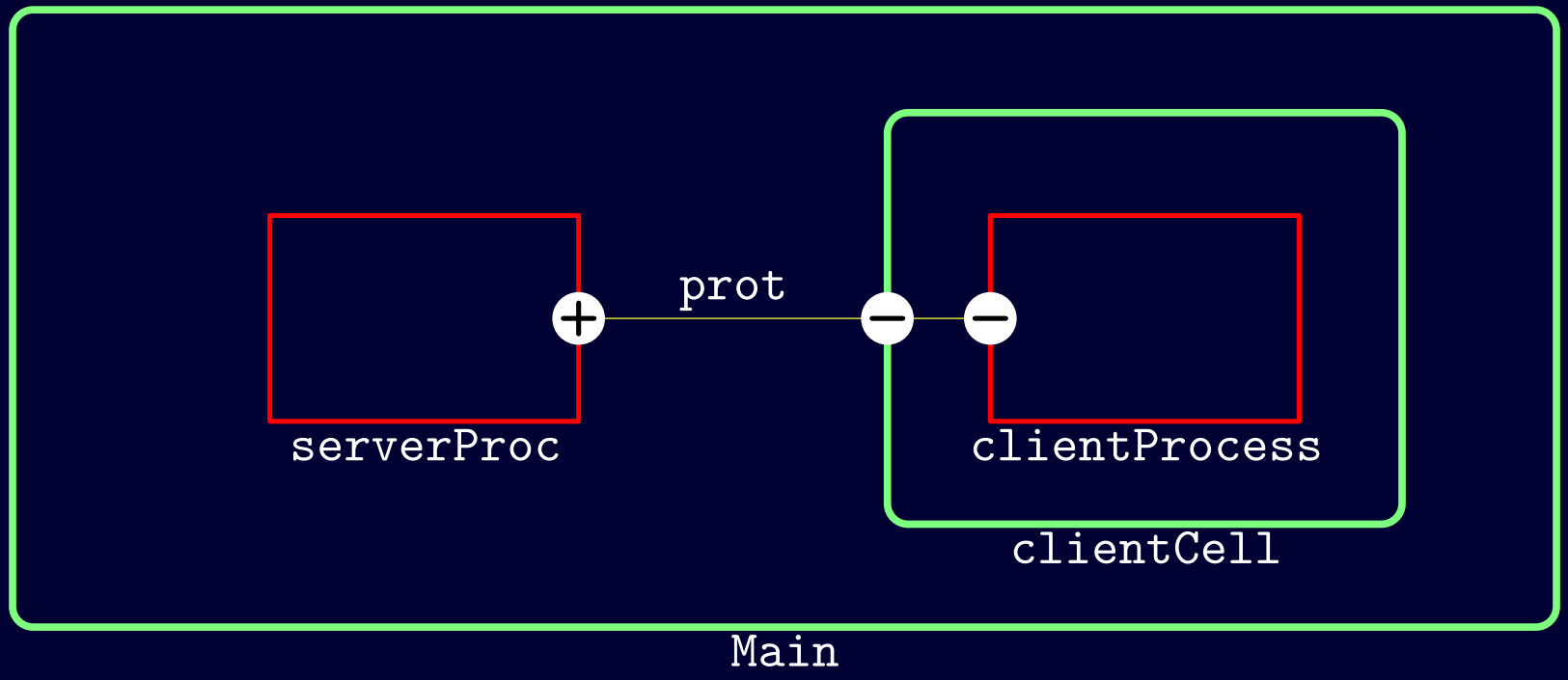
```
prot = [ start; *( query: Text; ^reply: Integer ); stop ];

serverProc = { p +: prot |
  p.start;
  loopselect
    || input: Text := p.query; p.reply := 0
    || p.stop; exit
  end
};

clientCell = ( p -: prot | );

Main = ( p :: prot; serverProc(p); clientCell(p) );

Main();
```




```
clientProc = { p -: prot | };

clientCell = ( p -: prot | clientProc(p) );
```

Protocols

```
query = [ question; ^answer ]

sequence = [
    first: Integer;
    second: Text;
    third: Float ]

method1 = [ *( arg1; arg2; ...; ^result ) ]

method2 = [ *( arg1; arg2; ...; ^res1; ^res2 ) ]

class = [ *( M1 | M2 | ... | Mn ) ]
```

Statements

```
select
  || p.red; ...
  || p.yellow; ...
  || p.green; ...
end

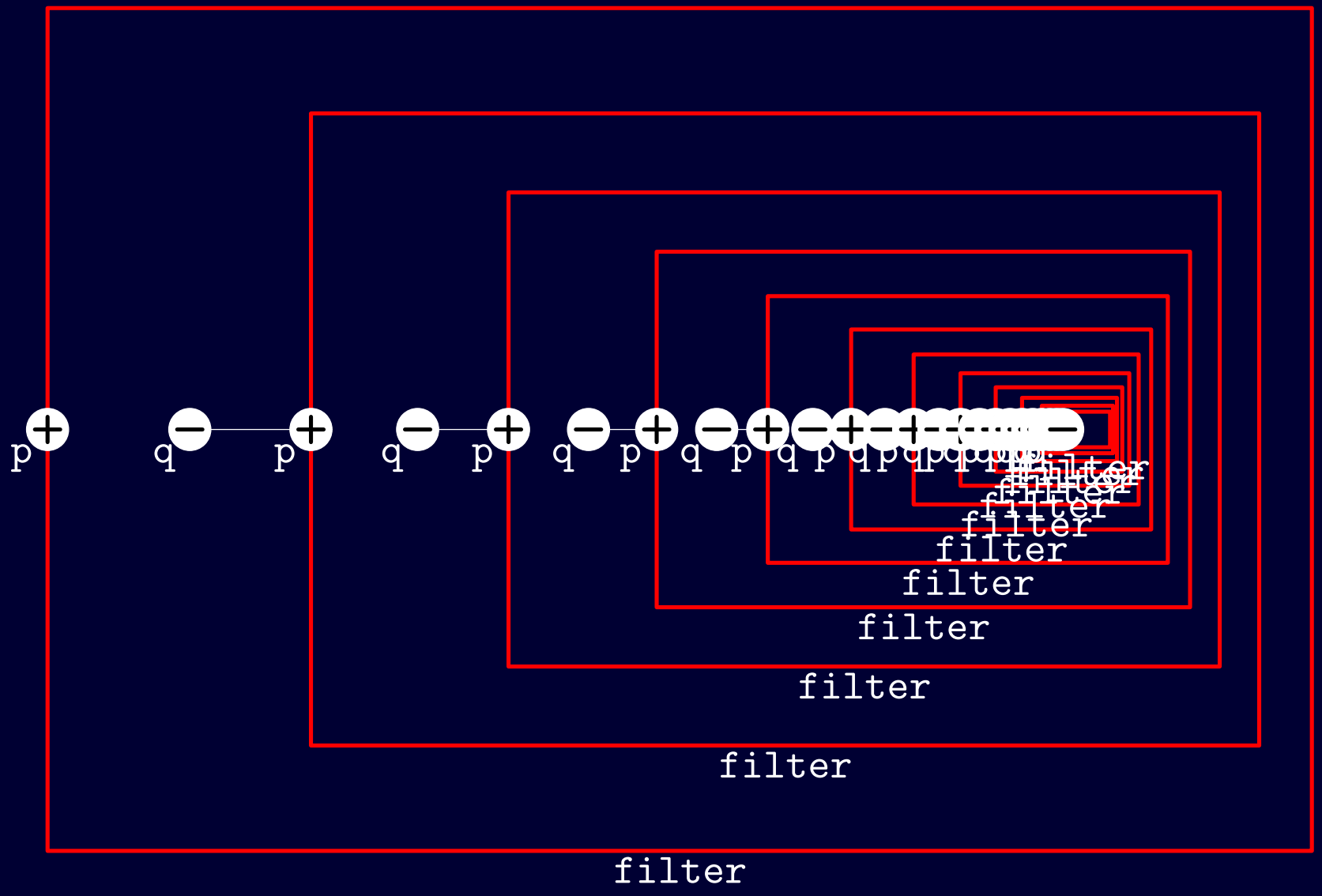
select
   |stored < 10| buff[i] := p.x; ...
   |stored > 0| q.y := buff[j]; ...
end

select fair ...
select ordered ...
select random ...
```

Processes

```
prot = [ *( arg: Integer ) ];

filter = { p +: prot |
  prime: Integer := p.arg;
  sys.out := text prime + ' ';
  q -: prot;
  filter(q);
  loop
    n: Integer := p.arg;
    if n % prime != 0
      then q.arg := n
    end
  end
};
```


p
q
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filter
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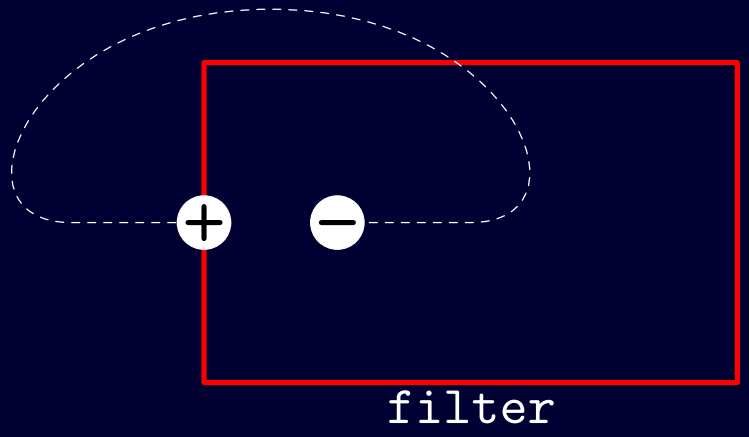
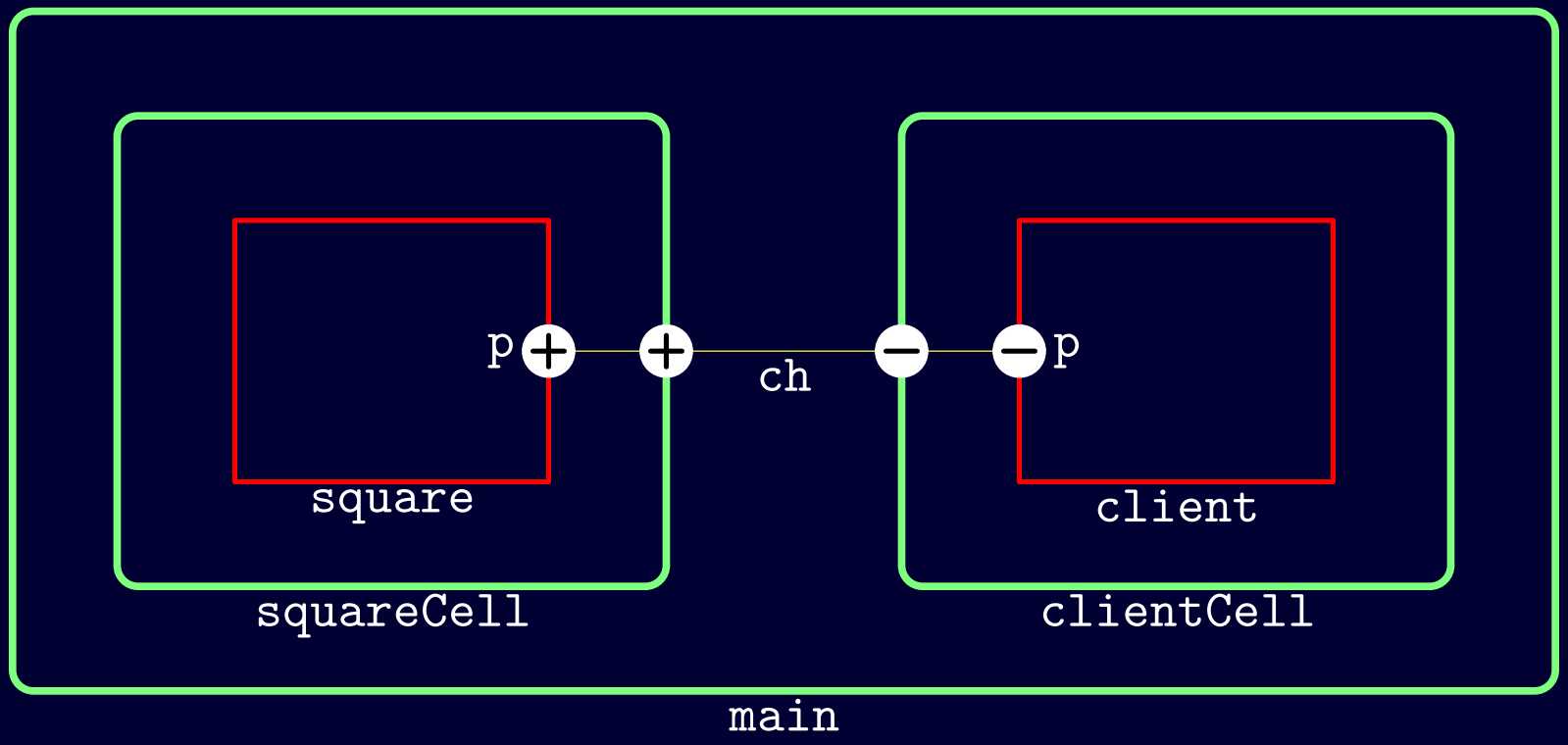
filter


filter

Semantics vs. Deployment



Code

```
sqProt = [ *( query: Float; ^reply: Text ) ];
square = { p +: sqProt |
  loop
     q: Float := p.query;
     p.reply := text(q * q);
  end
};
squareCell = ( port +: sqProt | square(port) );
client = { p -: sqProt |
   p.query := 2;
   sys.out := p.reply + "\n";
};
clientCell = ( port -: sqProt | client(port) );
main = ( ch :: sqProt; squareCell(ch); clientCell(ch) );
main();
```

Metacode

```
<Mapping>
  <Processor> alpha.encs.concordia.ca
     <Port> 5555 </Port>
     <Cell> squareCell </Cell>
     <Cell> clientCell1 </Cell>
  </Processor>
  <Processor> beta.encs.concordia.ca
     <Port> 5555 </Port>
     <Cell> squareCell1 </Cell>
     <Cell> clientCell </Cell>
  </Processor>
</Mapping>
```

Cells

- Programs consist of cells
- Cells may contain variables, processes, and cells
- Cells can be of any size

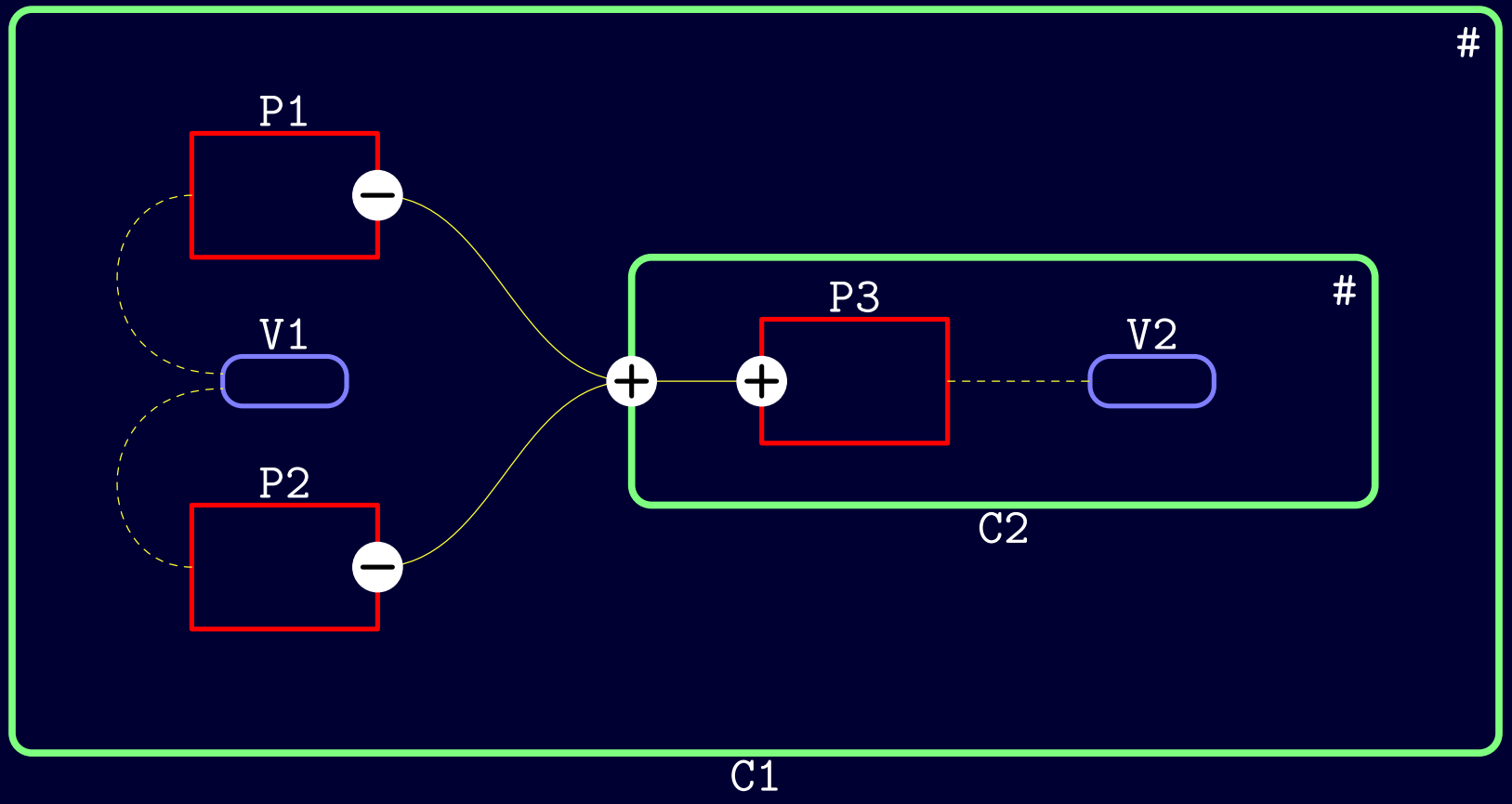
programs are "fractal"

- Cells are "first-class citizens"
- Control flow never crosses a cell boundary
- Cells are explicitly provided with all needed resources
- Cells may exchange messages
- Processes within a cell behave as co-routines

Processes

- A process is always inside a cell
- Processes may contain variables, processes, and cells
- Processes are "first-class citizens"
- All actions are performed within processes
- Control flow never crosses a process boundary
- A process may access variables within its cell
- Processes communicate by exchanging messages
- A process relinquishes control when it communicates

no race conditions



One program counter per cell

Protocols

- Protocols define interfaces
- Protocols specify communication patterns
- Protocols consist of typed messages and signals
- Protocols define sequence, choice, and repetition
- There is a "satisfaction" relation on protocols

Messages

- A "sent" message is an lvalue:

```
p.result := 42;
```

- A "received" message is an rvalue:

```
sum := p.val + ...;
```

- Signals synchronize:

```
p.stop
```

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```

- Signals synchronize:

```
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```

Separation of Concern

Cells define structure $\sim$ Processes define action

Code defines meanings $\sim$ Metacode defines deployment

Protocols specify processes $\sim$ Protocols ensure satisfaction

The case against

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- It's been tried before

  (CSP, occam, Joyce, Amber, Erlang, Hermes, . . .)

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- Programming languages are not the problem

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  (CSP, occam, Joyce, Amber, Erlang, Hermes, . . .)
- Programming languages are not the problem
- Object-oriented programming is good enough

The case against

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- Programming languages are not the problem
- Aspect-oriented programming is good enough

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- Programming languages are not the problem
- Aspect-oriented programming is good enough
- We've hidden the hard bits

  3-tier: CICS, J2EE, CORBA, ...

The case against

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  (CSP, occam, Joyce, Amber, Erlang, Hermes, . . .)

- Programming languages are not the problem
- Aspect-oriented programming is good enough
- We've hidden the hard bits

  3-tier: CICS, J2EE, CORBA, ...

- Introducing a new paradigm is no longer feasible

The case for

The case for

- Many distributed applications

The case for

- Many distributed applications
- Multicore processors

The case for

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- Process-oriented programming is ... good

The case for

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We need software
- development
- maintenance
- growth
- adaptation
- evolution
- refactoring

The End

</Keynote>