CO405H

Computing in Space with OpenSPL

Topic 3: OpenSPL

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WebIDE: http://openspl.doc.ic.ac.uk
OpenSPL consortium page: http://www.openspl.org

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Overview

- Introduction to the Basics
- Architecture
- Spatial Substrates
- Control flow in Space

OpenSPL to drive Computing in Space

Dec 10, 2013. London. OpenSPL is being announced at the Bloomberg Enterprise Technology Summit in London. CME, Juniper, Chevron and Maxeler are forming the founding team of companies to drive OpenSPL in their respective markets. Founding academic members are Stanford, Imperial College London, Tsinghua University in Beijing and the University of Tokyo.

Dec 10, 2013. London. The OpenSPL consortium is announcing the first OpenSPL Summer School in July 2014, at Imperial College London. The Summer School will bring together researchers, students, and members of OpenSPL to share experiences, application development, and continue to develop the science behind computing in space.

Dec 9, 2013. Chicago. Ari Studnitzer at CME Group has published a blog on OpenMarket about the announcement of OpenSPL and OpenSPL-compliant technology from the CME. “Our new, patent-pending iLink Market Segment gateway will provide inline pre-trade credit controls, unparalleled predictability, advanced market controls, as well as increased capacity and throughput.”

- Founding Corporations:

Chevron Human Energy · CME Group · Juniper Networks · Maxeler Technologies Maximum Performance Computing

- Academic Partners:

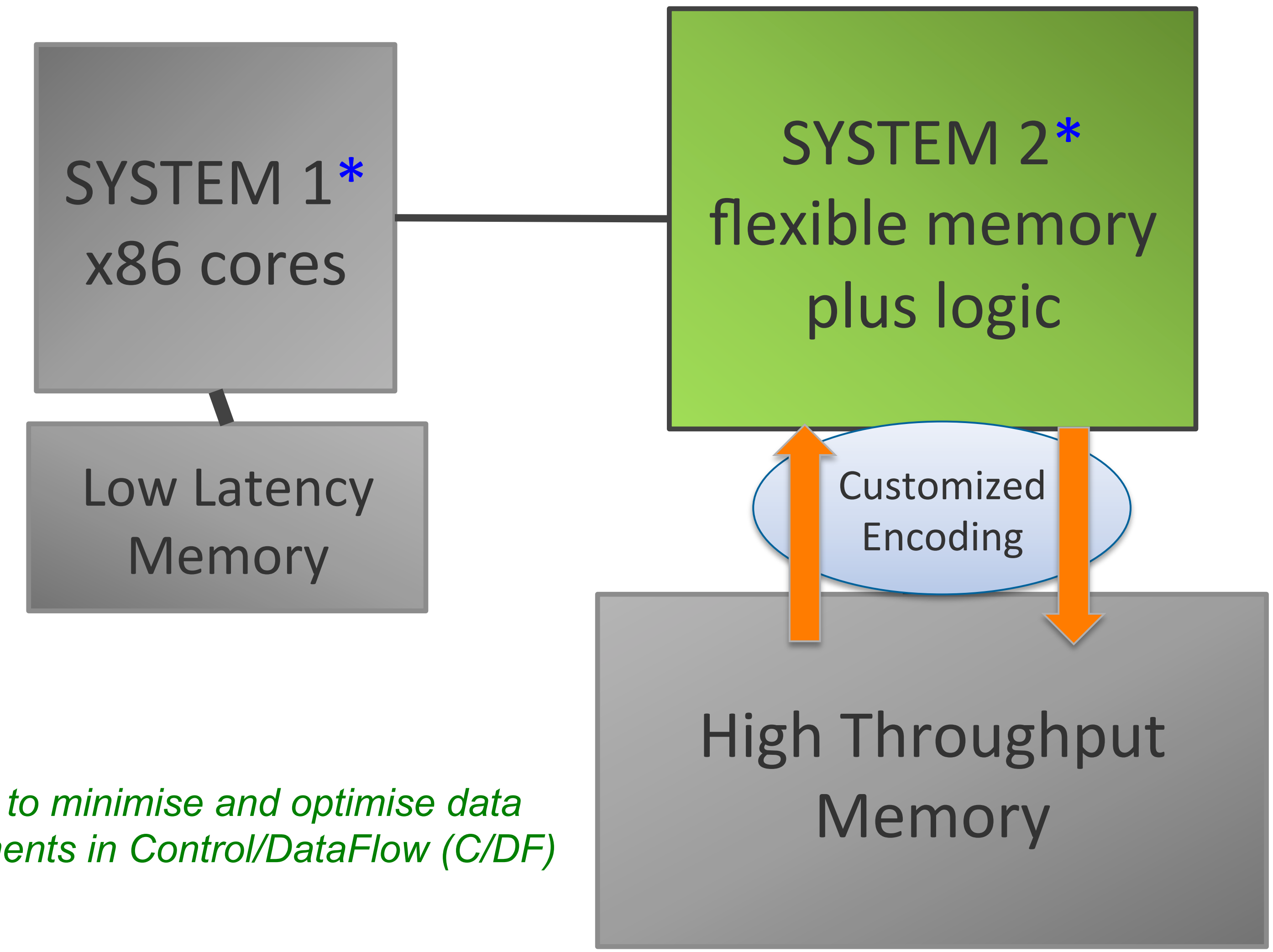
Imperial College London · Stanford · 東京大学 The University of Tokyo · 清華大学 Tsinghua University

OpenSPL

http://www.OpenSPL.org

launched on Dec 9, 2013

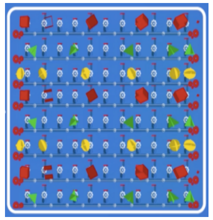
The Combined Control/DataFlow system



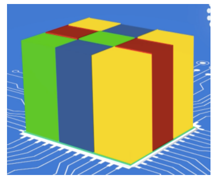
Goal is to minimise and optimise data movements in Control/DataFlow (C/DF)

*** System 1 and System 2 are based on D Kahneman,**
"Thinking Fast Thinking Slow", Nobel Prize in Economics, 2002

OpenSPL basics



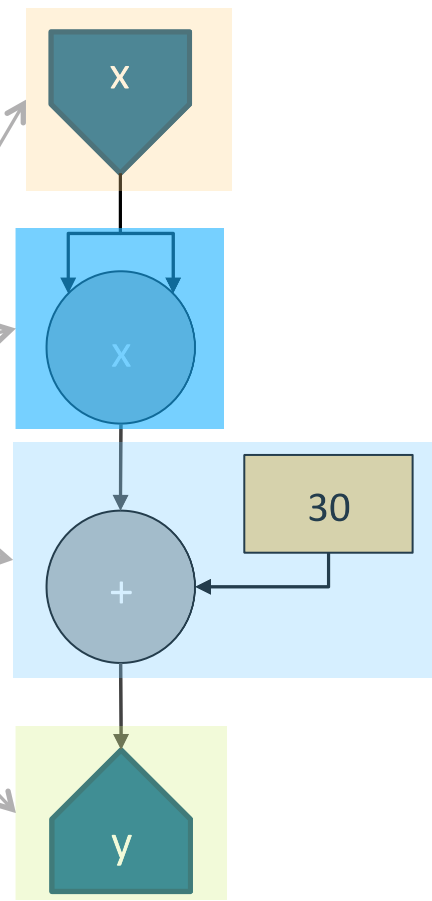
- Control and Data-flows are decoupled
  - Both are fully programmable
- Operations exist in space and by default run in parallel
  - Their number is limited only by the available space
- All operations can be customized at various levels
  - e.g., from algorithm down to the number representation
- Multiple operations constitute kernels
- Data streams through the operations / kernels
- The data transport and processing can be balanced
- All resources work all of the time for max performance
- The In/Out data rates determine the operating frequency



Equally spread the available “forces” and move no faster than required by the application

OpenSPL example: $X^2 + 30$

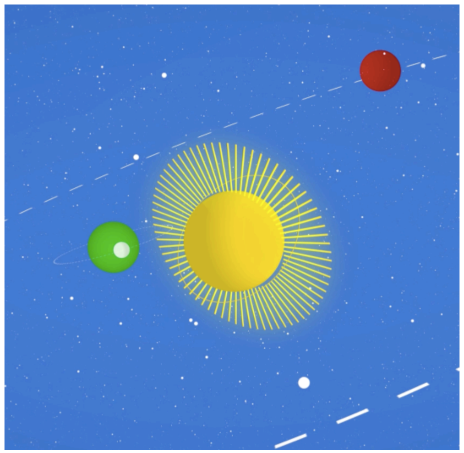
```
SCSVar x = io.input("x", scsInt(11));

SCSVar result = x * x + 30;

io.output("y", result, scsInt(23));
```

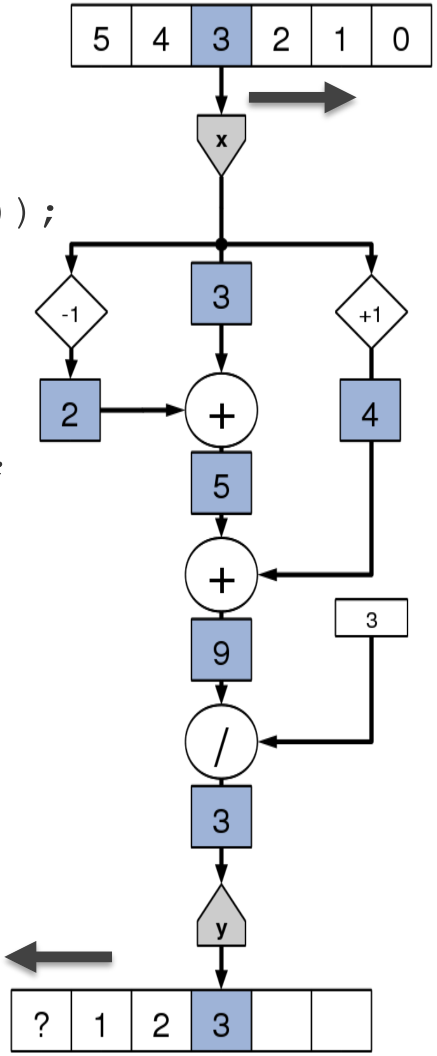


OpenSPL

OpenSPL example: Moving Average

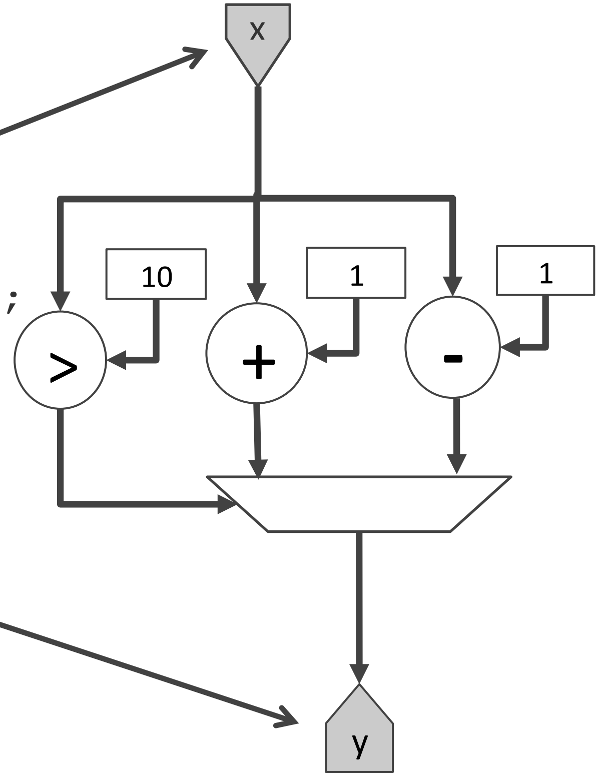
```
class MovingAvgKernel extends Kernel {
    MovingAvgKernel() {
        SCSVar x = io.input("x", scsFloat(7,17));
        SCSVar prev = stream.offset(x, -1);
        SCSVar next = stream.offset(x,  1);
        SCSVar sum = prev + x + next;
        SCSVar result = sum / 3;
        io.output("y", result, scsFloat(7,17));
    }
}
```

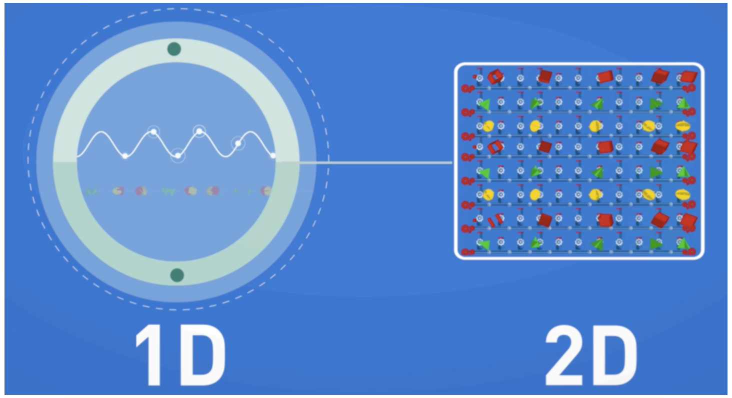




OpenSPL example: Control in Space

```
class SimpleKernel extends Kernel {
    SimpleKernel() {
        SCSVar x = io.input("x", scsFix(24));
        SCSVar result = (x>10) ? x+1 : x-1;
        io.output("y", result, scsFix(25));
    }
}
```





The OpenSPL Machine model

- A Spatial Computing system consists of:
  - a *Spatial Computing Substrate* (SCS):
    "hardware" technology with flexible arithmetic units
    and programmable interconnect
  - SCS specific compilation toolchain
  - SCS specific runtime system and all low level software
- Three basic memory types:
  - Scalars
  - Fast Memory (FMEM): small and fast
  - Large Memory (LMEM): large and slow

Fast and Slow

John von Neumann, 1946:

“We are forced to recognize the possibility of constructing a hierarchy of memories, each of which has greater capacity than the preceding, but which is less quickly accessible.”

The OpenSPL Machine model (cont)

- Computational kernels interconnected by data flow streams to form bigger entities called *actions*

- Action is the basic the Spatial Computing Substrate (SCS) execution unit and performs as a single entity

- In a spatial system one or more SCS engines exist, each executing a single action at any moment in time

Spatial Arithmetic

- Operations instantiated as separate arithmetic units
- Units along data paths use custom arithmetic and number representation (as long data stays correct)
- The above may reduce individual unit sizes (and maximizes the number that fits a given SCS)
- Data rates of memory and I/O communication may also be maximized due to scaled down data sizes

Spatial Arithmetic at all levels

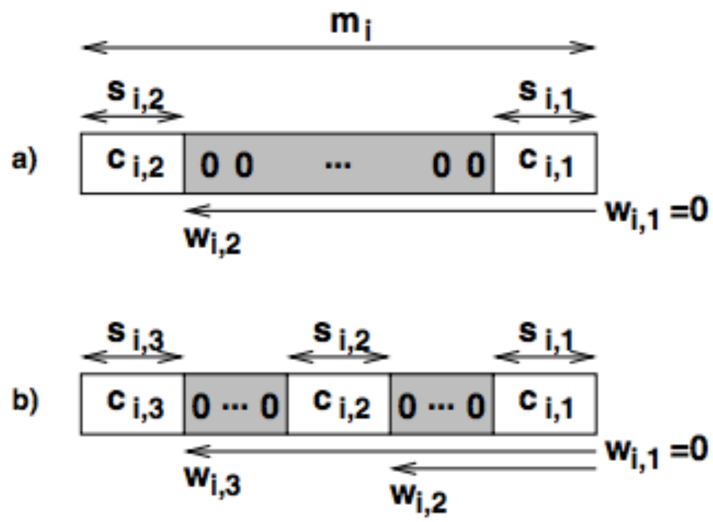
- Arithmetic optimizations at the **bit level**
  - e.g., minimizing the number of '1's in binary numbers, leading to linear savings of both space and power (the zeros are omitted in the implementation)
- **Higher level arithmetic** optimizations
  - e.g., in matrix algebra, the location of all non-zero elements in sparse matrix computations is important
- Spatial **encoding of data** structures can reduce transfers between memory and computational units (boost performance and improve efficiency)
  - In temporal computing encoding and decoding would take time and eventually can cancel out all of the advantages
  - In spatial computing, encoding and decoding just consume a bit more of additional space

OpenSPL enabled optimizations

Multiple scales of computing	Important features for optimization
complete system level	$\Rightarrow$ balance compute, storage and IO
parallel node level	$\Rightarrow$ maximize utilization of compute and interconnect
microarchitecture level	$\Rightarrow$ minimize data movement
arithmetic level	$\Rightarrow$ tradeoff range, precision and accuracy = discretize in time, space and value
bit level	$\Rightarrow$ encode and add redundancy
transistor level	=> create the illusion of '0' and '1'

And more, e.g., trade Communication (Time) for Computation (Space)

Expl: Minimize ‘1’s => Sparse Coefficients



$$p = \frac{32799}{32768} - \frac{609}{32768}x - \frac{14881}{32768}x^2.$$

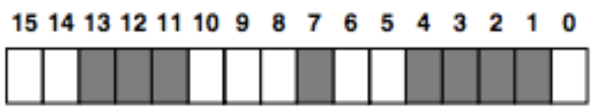


Fig. 2. Target format for cos function.

$$p = -\frac{75}{32768} + \frac{34538}{32768}x - \frac{6169}{32768}x^2.$$

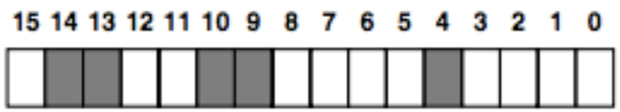


Fig. 3. Target format for sin function.

$$p = \frac{32793}{32768} + \frac{31836}{32768}x + \frac{21146}{32768}x^2.$$

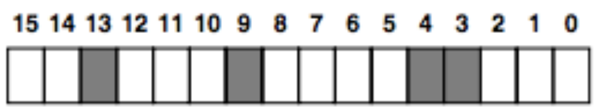


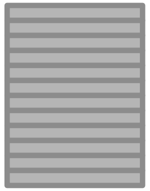
Fig. 4. Target format for exp function.

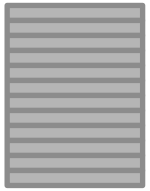
Nicolas Brisebarre, Jean-Michel Muller and Arnaud Tisserand
Sparse Coefficient Polynomial Approximations for Hardware Implementation,
Asilomar Conference, 2004.

Computation / Memory considerations

Computing f(x) in the range [a,b] with $|E| \leq 2^{-n}$

Table *Table+Arithmetic* *Arithmetic*



 and +,-,×,÷

+,-,×,÷

- uniform vs non-uniform
- number of table entries
- how many coefficients

- polynomial or rational approx
- continued fractions
- multi-partite tables

Underlying hardware/technology changes the optimum

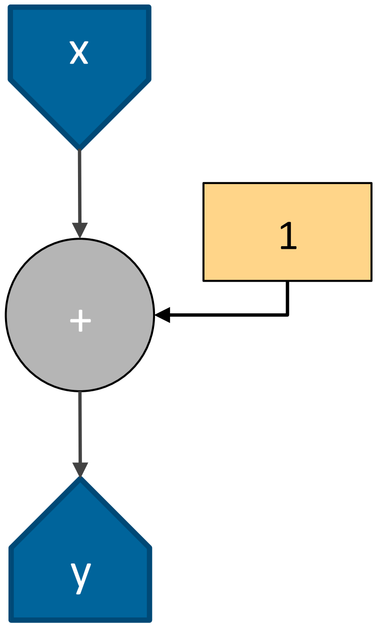
OpenSPL meta-programming

- You can use the full power of your language of choice, e.g., Java, to write a program that *generates* the dataflow graph
- Variables can be used as constants in hardware (actually wires)
  - int y; SCSVar x; x = x + y;
- Hardware variables do not "exist" at compile time!
  - Cannot do: int y; SCSVar x; y = x;
- Conditionals and loops choose *how* to generate hardware → not make run-time decisions

Dataflow Graph Generation: Simple

What dataflow graph is generated?

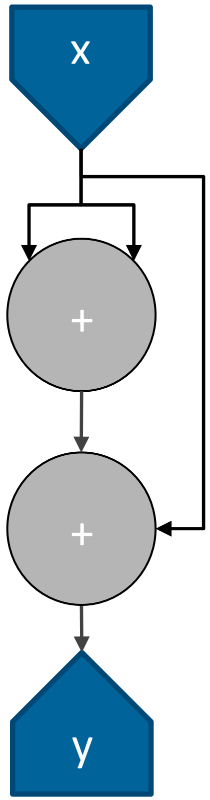
```
SCSVar x = io.input("x", <type>);
SCSVar y;
int CON = 1;

y = x + CON;

io.output("y", y, <type>);
```

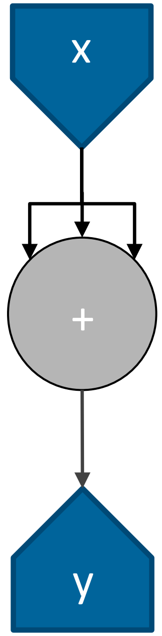


Dataflow Graph Generation: Simple

What dataflow graph is generated?

```
SCSVar x = io.input(“x”, <type>);
SCSVar y;

y = x + x + x;

io.output(“y”, y, <type>);
```

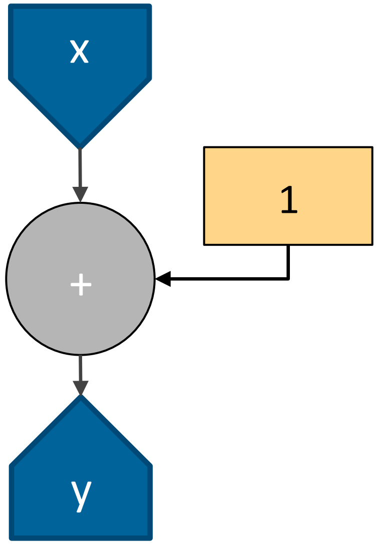




Dataflow Graph Generation: Conditionals

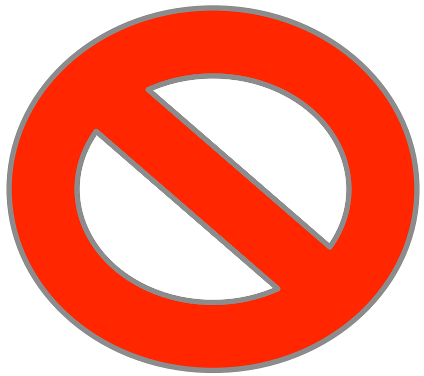
What dataflow graph is generated?

```
SCSVar x = io.input("x", <type>);
int s = 10;
SCSVar y;

if (s < 100) { y = x + 1; }
else { y = x - 1; }

io.output("y", y, <type>);
```



What dataflow graph is generated?

```
SCSVar x = io.input("x", <type>);
SCSVar y;

if (x < 10) { y = x + 1; }
else { y = x - 1; }

io.output("y", y, <type>);
```



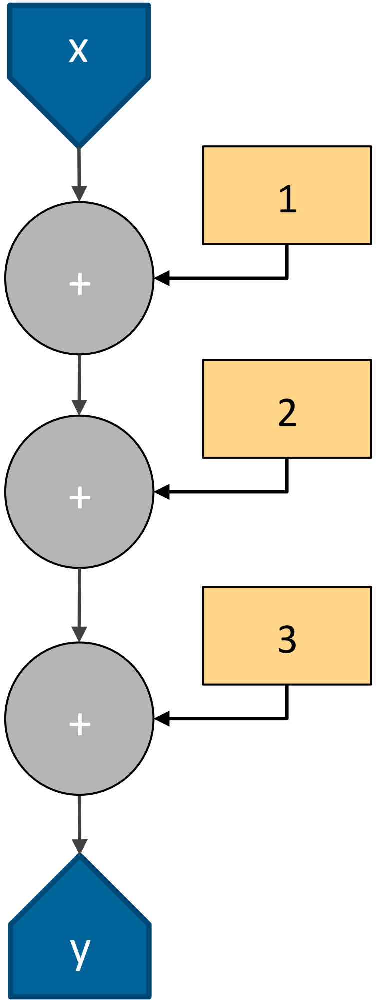
Compile error.

You can't use the value of stream 'x' in a meta conditional

Dataflow Graph Generation: Loops

What dataflow graph is generated?

```
SCSVar x = io.input("x", <type>);
SCSVar y = x;
for (int i = 1; i <= 3; i++) {
        y = y + i;
}
io.output("y", y, <type>);
```



Can make the loop any size – until you run out of space on the chip!

Larger loops can be partially unrolled in space and reused multiple times in time

If-Else Statements

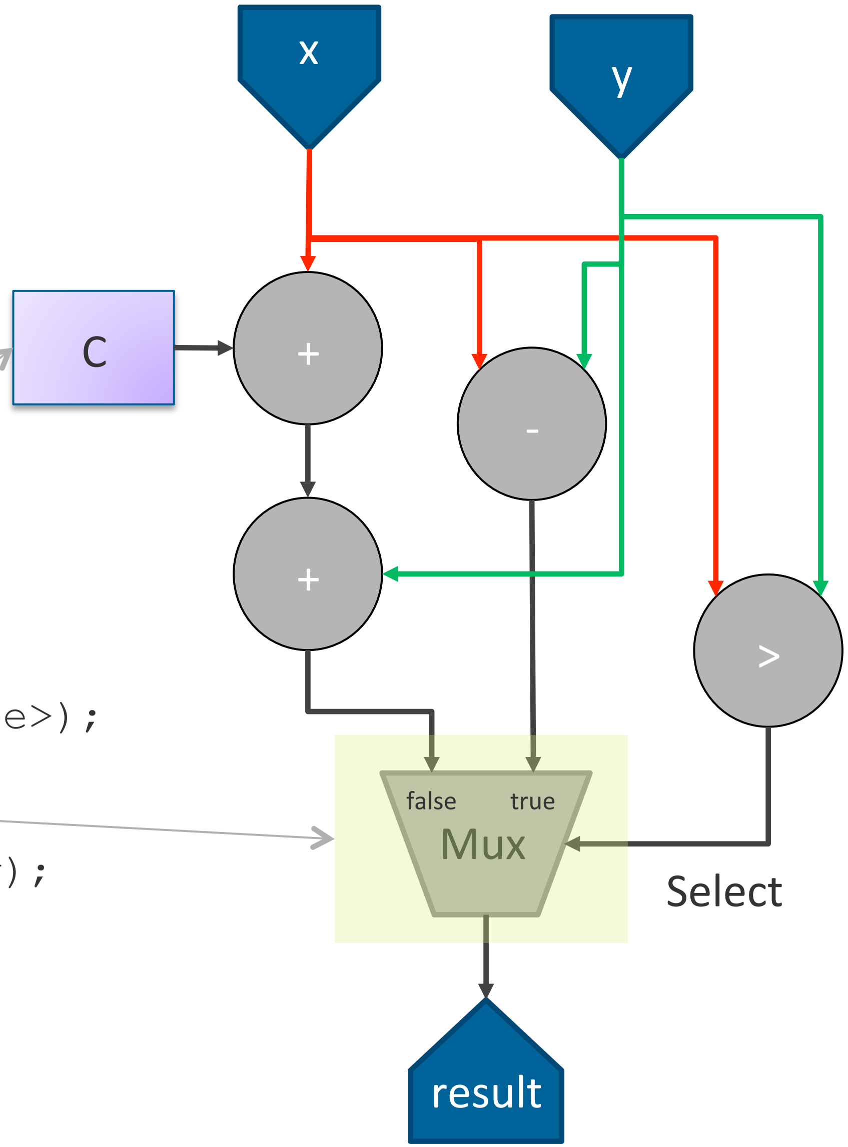
- Data dependent conditional statements are common
- How can we implement this in OpenSPL?

```
int C = 500;
for (int i = 0; i < N; i++) {
      if (x[i] > y[i])
         result[i] = x[i] - y[i];
      else
         result[i] = C + x[i] + y[i];
}
```

Control Flow in Space
If-Else = Mux

What’s this scalar input?

```
SCSVar x = io.input("x", <type>);
SCSVar y = io.input("y", <type>);
SCSVar C = io.scalarInput("C", <type>);

SCSVar result = x > y ?
                (x - y) : (C + x + y);
```



Scalar Inputs for efficiency

- Consider:

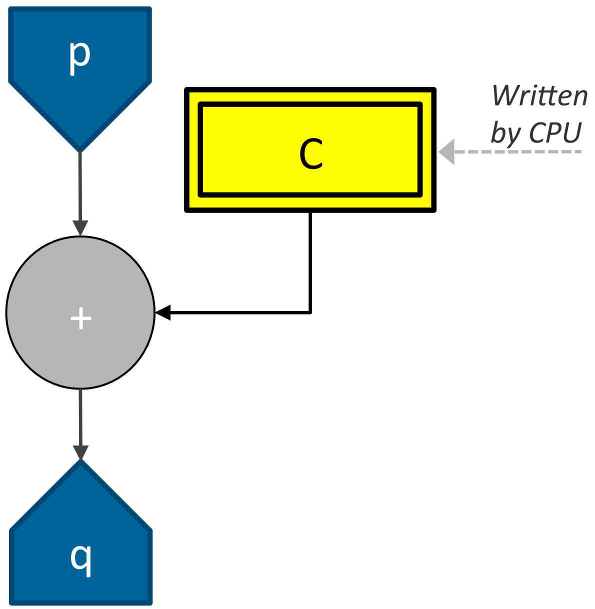
```
void fn1(int N, int *q, int *p) {
    for (int i = 0; i < N; i++)
        q[i] = p[i] + 4;
}
```

vs.

```
void fn2(int N, int *q, int *p, int C) {
    for (int i = 0; i < N; i++)
        q[i] = p[i] + C;
}
```

- In fn2, we can change the value of C without recompiling, but it is constant for the whole loop
- OpenSPL equivalent:

```
SCSVar p = io.input("p", scsInt(32));
SCSVar C = io.scalarInput("C", scsInt(32));

SCSVar q = p + C;

io.output("q", q, scsInt(32));
```



OpenSPL Instantiation Requirements

To comply with OpenSPL one has to have:

- Spatial (customizable) Computing Substrate
  - Compute (arithmetic) fabric
  - Memory system
  - IO / Networking
- Spatial Compiler (incl specific place and route tools)
- OS (or runtime OS extension)
- Support for customizable Data Orchestration
- (optional) Domain specific languages and libraries

Summary

- OpenSPL prescribes all the levels of a Spatial Computing System
- OpenSPL provides programmers with powerful constructs for 2D compute fabric customization
- OpenSPL enables mapping computation in space and hence performance improvements
- OpenSPL is SCS independent but performance optimizations are highly algorithm and SCS specific
- OpenSPL requires revolutionary way of thinking about computing systems