Data-Parallel Programming using SaC
lecture 2

F21DP Distributed and Parallel Technology

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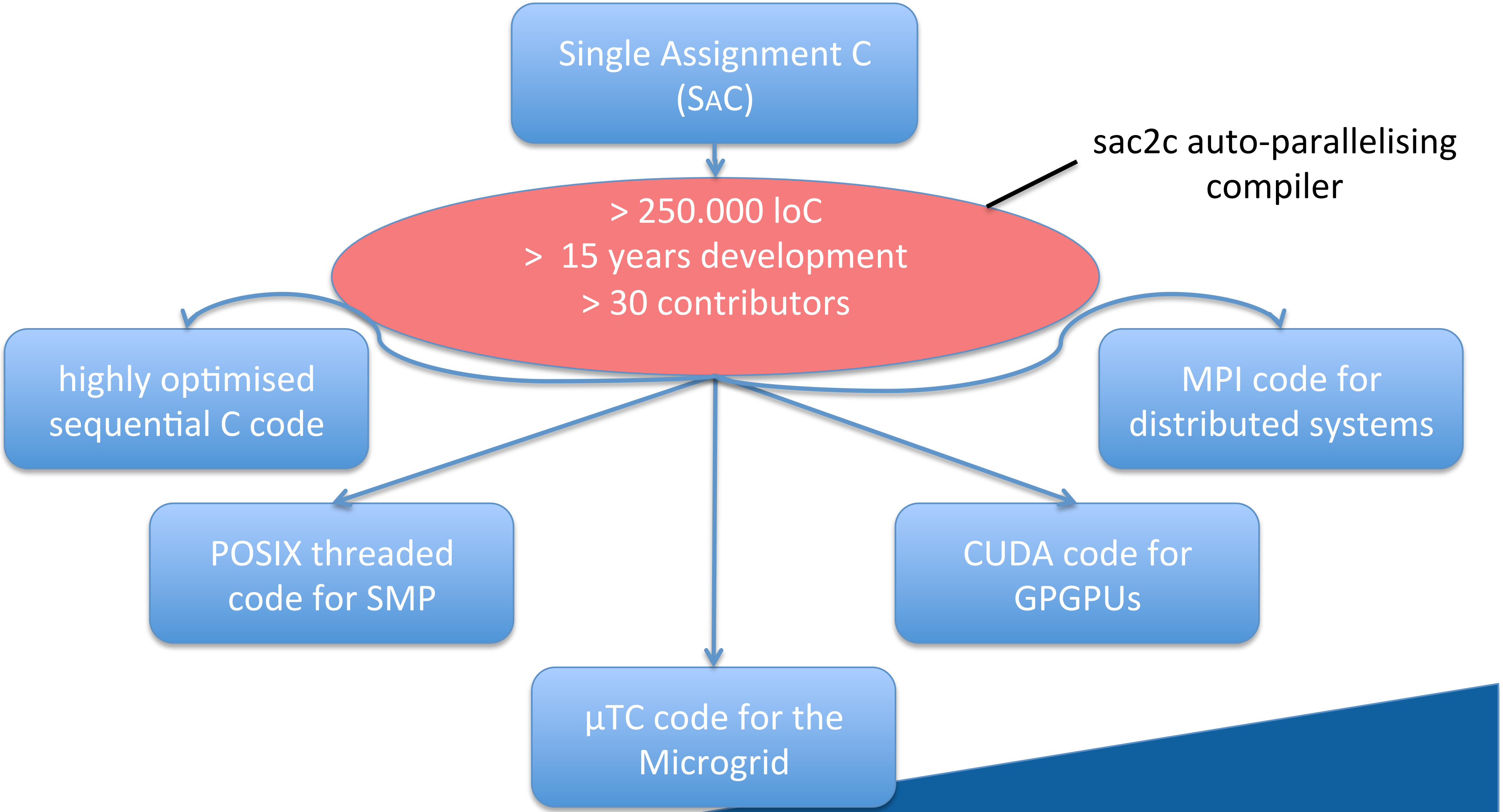
The Big Picture



Single Assignment C (SAC)

sac2c auto-parallelising compiler

> 250.000 loC
> 15 years development
> 30 contributors

highly optimised sequential C code

MPI code for distributed systems

POSIX threaded code for SMP

CUDA code for GPGPUs

µTC code for the Microgrid

SAC: HP^2 Driven Language Design

HIGH-PRODUCTIVITY

- easy to learn
  - C-like look and feel
- easy to program
  - Matlab-like style
  - OO-like power
  - FP-like abstractions
- easy to integrate
  - light-weight C interface

&

HIGH-PERFORMANCE

- no frills
  - lean language core
- performance focus
  - strictly controlled side-effects
  - implicit memory management
- concurrency apt
  - data-parallelism at core

SAC: Basic Principles

- Purely Functional Core
    - enables radical transformations
- Subtyping and Overloading
    - enables high reuse
- Pervasive Array Programming
    - enables massive concurrency

The Functional Programming Perspective

- What not How
  - close to the algorithm
  - no resource / cost awareness
- Features Abstraction
  - generic specifications
  - elaborate type systems
- Consequences:

  + high programming productivity
  + high code reuse
  + high potential for code-modication
  - huge semantic gap

What not How (1)

re-computation **not** considered harmful!

```
a = potential( firstDerivative(x));
a = kinetic( firstDerivative(x));
```

What not How (1)

re-computation **not** considered harmful!

```
a = potential( firstDerivative(x));
a = kinetic( firstDerivative(x));
```

compiler

```
tmp = firstDerivative(x);
a = potential( tmp);
a = kinetic( tmp);
```

What not How (2)

variable declaration **not** required!

```
int main()
{
    istep = 0;
    nstop = istep;
    x, y = init_grid();
    u = init_solv (x, y);
...
```

What not How (2)

variable declaration **not** required, ...

but sometimes useful!

```
int main()
{
    double[ 256] x,y;

    istep = 0;
    nstop = istep;
    x, y = init_grid();
    u = init_solv (x, y);
...
```

acts like an assertion here!

What not How (3)

data structures do **not** imply memory layout

```
a = [1,2,3,4];

b = genarray( [1024], 0.0);

c = stencilOperation( a);

d = stencilOperation( b);
```

What not How (3)

data structures do **not** imply memory layout

```
a = [1,2,3,4];

b = genarray( [1024], 0.0);

c = stencilOperation( a);

d = stencilOperation( b);
```

could be implemented by:

```
int a0 = 1;
int a1 = 2;
int a2 = 3;
int a3 = 4;
```

What not How (3)

data structures do **not** imply memory layout

```
a = [1,2,3,4];

b = genarray( [1024], 0.0);

c = stencilOperation( a);

d = stencilOperation( b);
```

or by:

```
int a[4] = {1,2,3,4};
```

What not How (3)

data structures do **not** imply memory layout

```
a = [1,2,3,4];

b = genarray( [1024], 0.0);

c = stencilOperation( a);

d = stencilOperation( b);
```

or by:

```
adesc_t a = malloc(...)
a->data = malloc(...)
a->data[0] = 1;
a->desc[1] = 2;
a->desc[2] = 3;
a->desc[3] = 4;
```

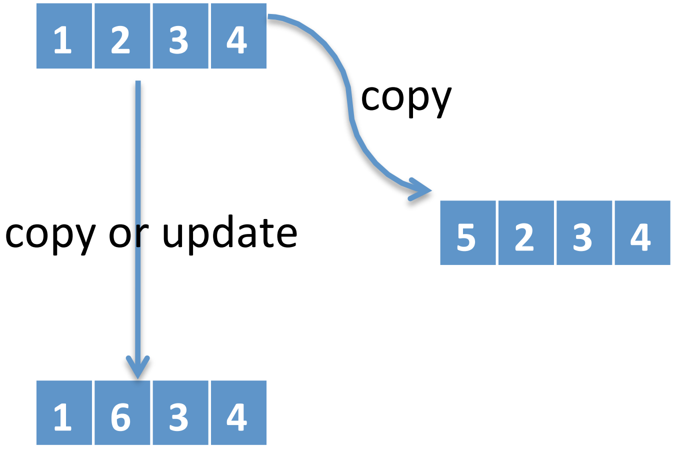
What not How (4)

data modification does **not** imply in-place operation!

```
a = [1,2,3,4];

b = modarray( a, [0], 5);

c = modarray( a, [1], 6);
```



What not How (5)

truely implicit memory management

```
qpt = transpose( qp);
deriv = dfDxBoundary( qpt);
qp = transpose( deriv);
```

≡

```
qp = transpose( dfDxNoBoundary( transpose( qp), DX));
```

Subtyping and Overloading

- Aims
  - extreme code reuse
  - multi-inheritance
- Consequences:

  \+ high programming productivity

  \+ high code reuse

  \- huge semantic gap

Subtyping in SaC

```
int[*] a;
int[.,.] m;
int[1,0] m2;

a = 2;
a = [[1,2],[3,4]];
m = [[1,2],[3,4]];
m = [[]];
m2 = [[]];
```

Function Overloading

```
double methodX( double[.,.] a, double[*] b)
{ ... }
double methodX( double[2,2] a, double[.,.] b)
{ ... }
double methodX( double[.,.] a, double b)
{ ... }
```

The Array Programming Perspective

- Everything is an Array!
- Index-Free, Combinator Style Computations
- Shape-Invariant Programming
- Consequences:

  + high programming productivity
  + excellent code maintainability
  + high potential for data-parallelism (!)
  - huge semantic gap

Basic Operations

```
dim(42) == 0
dim( [1,2,3]) == 1
dim([[1, 2, 3],
     [4, 5, 6]] ) == 2


shape( 42) == []
shape( [1, 2, 3]) == [3]
shape( [[1, 2, 3],
        [4, 5, 6]] ) == [2, 3]

a = [[1, 2, 3],
     [4, 5, 6]];
a[[1,0]] == 4
a[[1]] == [1,5,6]
a[[]] == a
```

The Usual Suspects

```
a = [1,2,3];
b = [4,4,2];

a+b == [5,6,5];
a<=b == [true, true, false];
sum(a) == 6
...
```

Matlab/ APL stuff

```
a = [[1,2,3],
     [4,5,6]];

take( [2,1], a) == [[1],
                    [4]]
take( [1], a) == [[1,2,3]] != [1,2,3]
take( [], a) == a

take( [-1, 2], a) == [[4,5]]

...
```

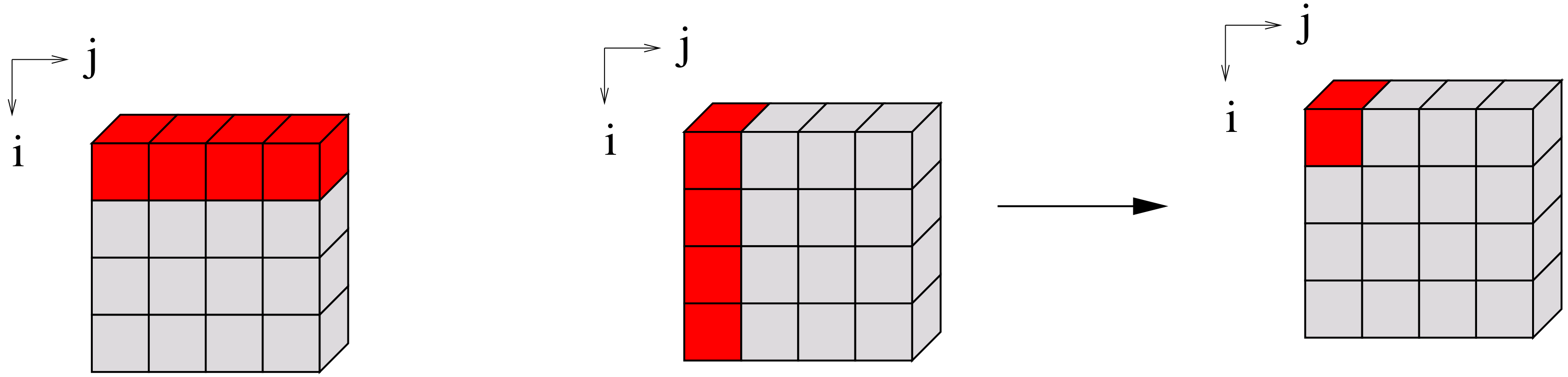
Set Notation

```
{ iv -> a[iv] + 1 } == a + 1

{ [i,j] -> mat[[j,i]] } == transpose( mat)

{ [i,j]->(i==j? mat[[i,j]]: 0)}
```

Example: Matrix Multiply

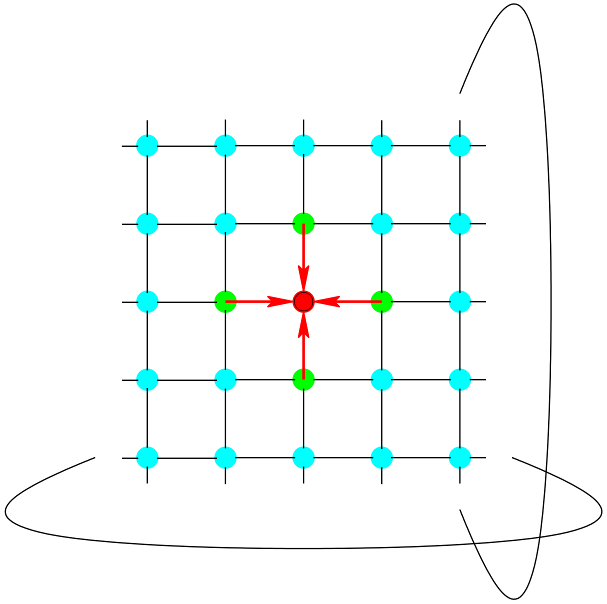


$$(AB)_{i,j} = \sum_{k} A_{i,k} * B_{k,j}$$

```
{ [i,j] -> sum( A[[i,.]]  * B[[.,j]]) }
```

Example: Relaxation

$$\begin{pmatrix} 0 & 1/8 & 0 \\ 1/8 & 4/8 & 1/8 \\ 0 & 1/8 & 0 \end{pmatrix}$$



```
weights = [ [0d, 1d, 0d], [1d, 4d, 1d], [ 0d, 1d, 0d]] / 8d
mat = ...
res = { [i,j] -> sum(
        { iv -> weights[iv] * rotate( iv-1, mat)}
                             [[...,i,j]] ) };
```

Getting Started: Hello World

```
use Structures : all;
use Numerical : all;
use StdIO : all;



int main() {
  printf(“hello world\n”);
  return( 0);
}
```

SaC Tool Chain

- sac2c – main compiler for generating executables; try
  - `sac2c –h`
  - `sac2c –o hello_world hello_world.sac`
  - `sac2c –mt`
  - `sac2c –t cuda`
- sac4c – creates C libraries from SaC libraries
- sac2tex – creates TeX docu from SaC files