Rethinking Language Design for Parallelization

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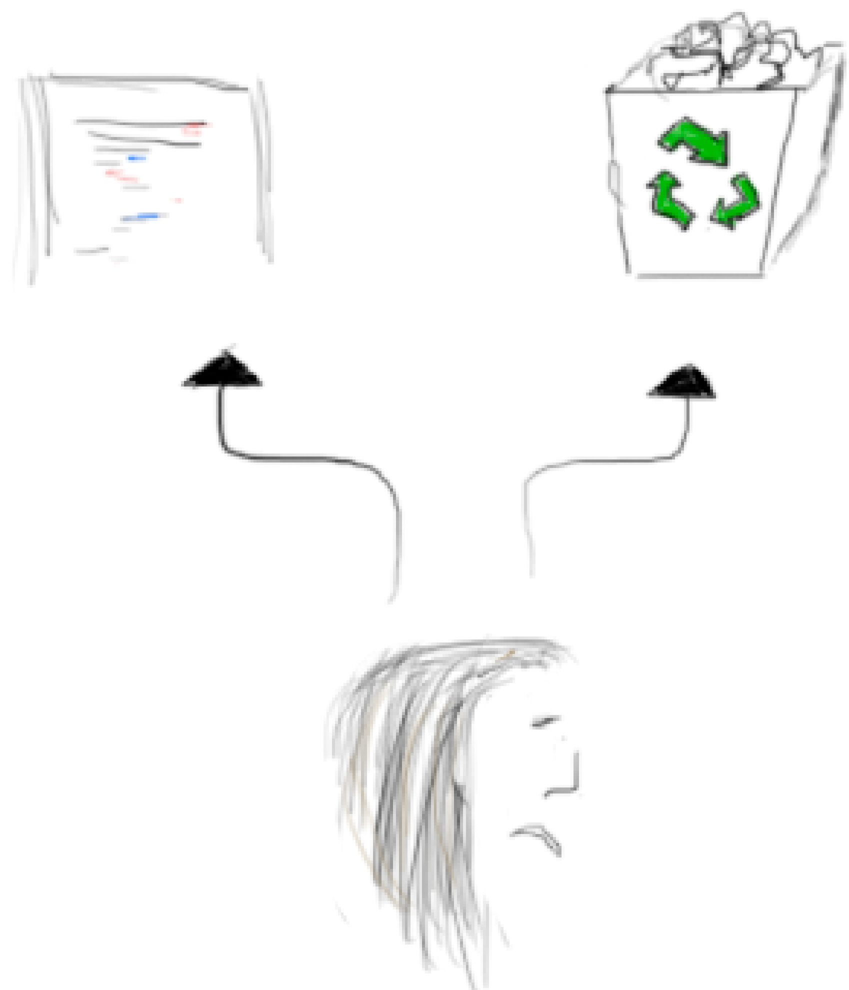
Friday 20th August, 2010
Intel, Santa Clara, CA

Work from the Cambridge Programming Research Group with Max Bolingbroke and Alan Mycroft

Properties: lost



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- Analysis + automatic transformation
- Manual

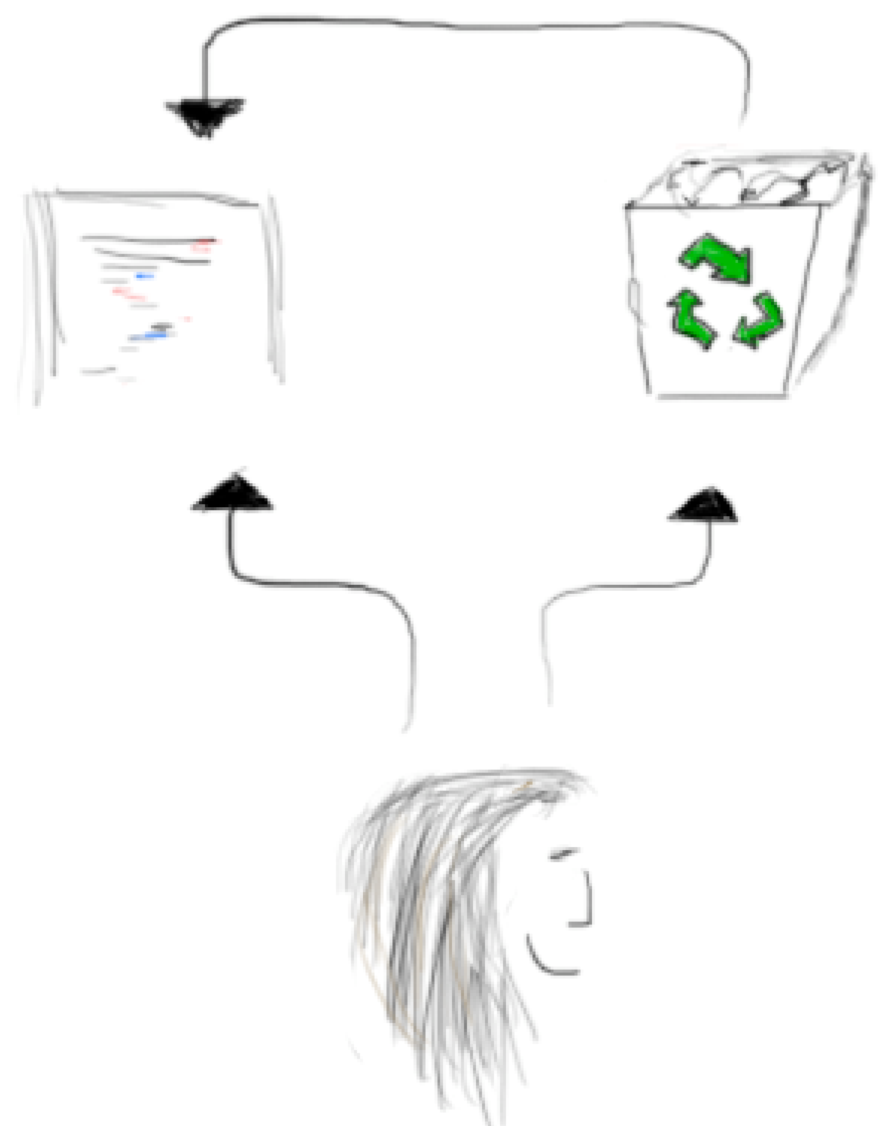
“Everything becomes clearer once you express it in the proper language.”

Greg Egan, *Schild’s Ladder*

Approach

Design a language to encode high-level program properties simply and directly

Properties: regained



A design approach

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- Declarative, abstract (not ***how*** but ***what***)
- Restricted => richer information encoding

Ypnos

- Ask about the name later!
- Haskell EDSL
- Data parallel programming with arrays
- User-instructed optimisation & parallelisation

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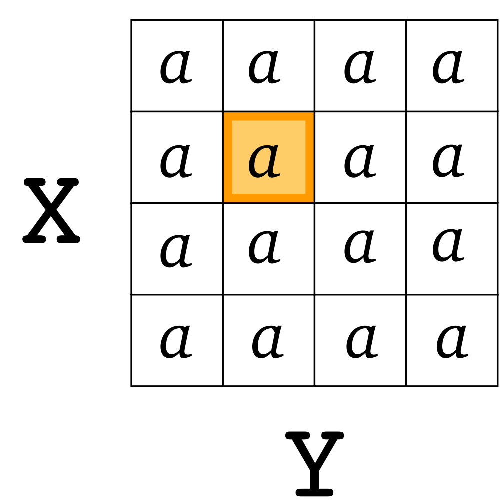

`:: Grid (X*Y) a`

Computational pattern

example: Laplace

```
while(condition) {
   for (int i=0; i<N; i++) {
     for (int j=0; j<M; j++) {
        Atemp[i][j] =
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- Called *mesh codes*, *stencil codes*, *kernels*, *structured grids*, *convolutions*, *gather operations*, *pixel shaders*

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while(condition) {
   for (int i=0; i<N; i++) {
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        Atemp[i][j] = f(A, i, j);
     }
   }
   swap(Atemp, A);
}

f(A, i, j) {
      ...
}
```

Computational pattern (2)

Kernel or *stencil* function:

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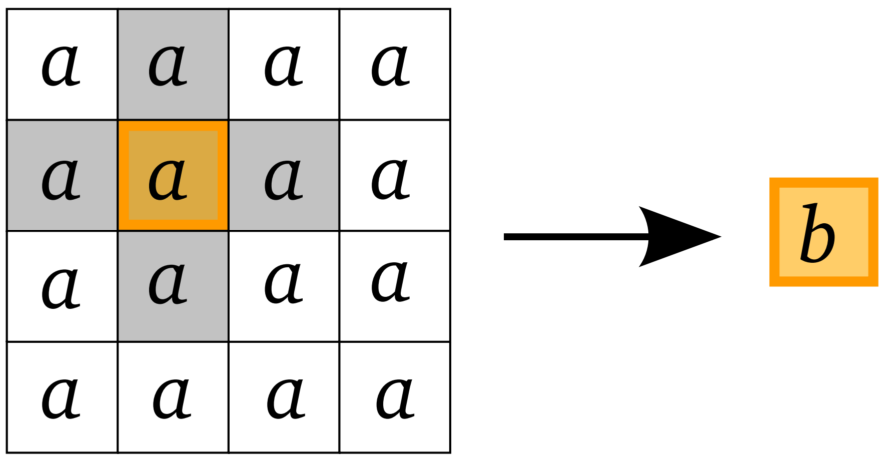

Computational pattern (3)

Apply the *stencil* function:

$$\texttt{run} :: (\texttt{Grid d a} \rightarrow \texttt{b}) \rightarrow (\texttt{Grid d a} \rightarrow \texttt{Grid d b})$$

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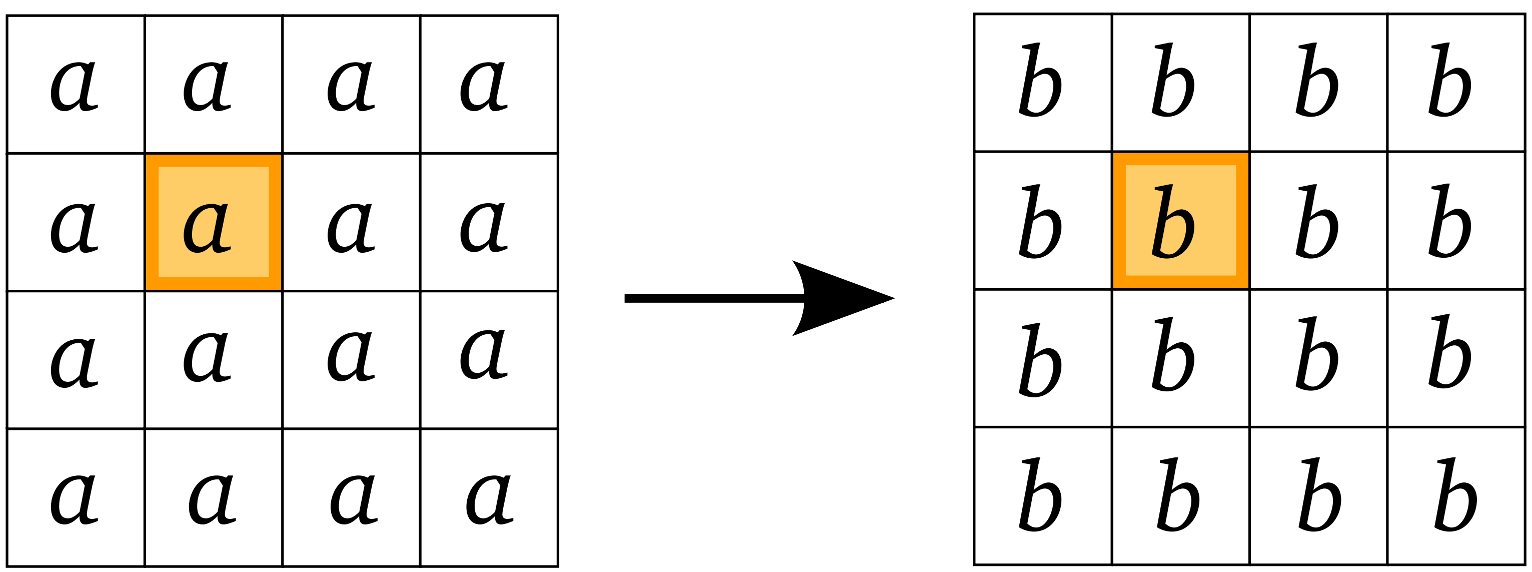

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    - `a[i][j]`, `a!!(i, j)`, `get(a, i, j)` etc.
- Allows random read/write
- Ypnos, *"Throw indexing to the dogs, I'll none of it!"*

Grid patterns

$$\texttt{f :: Grid X a} \rightarrow \texttt{b}$$

$$\texttt{f} \,|\texttt{l @c r}|\, = \texttt{...}$$

Grid patterns

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f ::  Grid X a → b
f |l @c r| = ...
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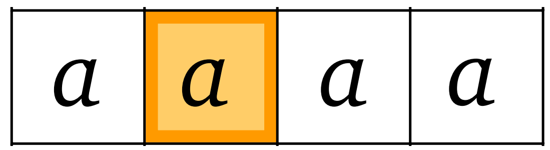

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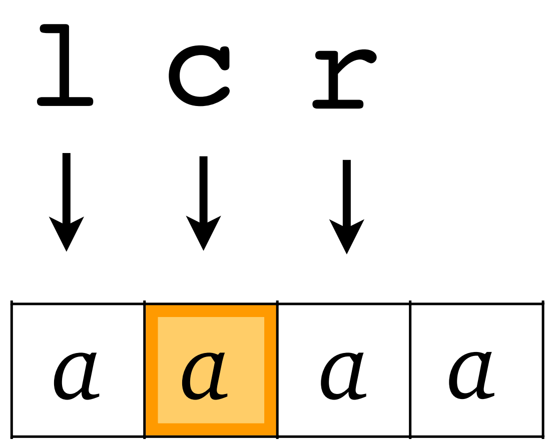

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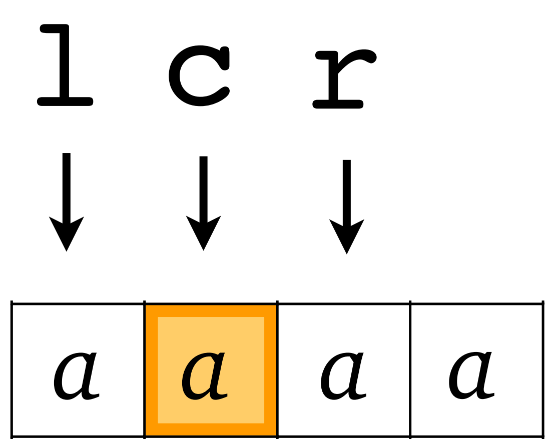


```
c = a[i]
l = a[i-1]
r = a[i+1]
```

Grid patterns (continued...)

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f ::  Grid (X × Y) a → b
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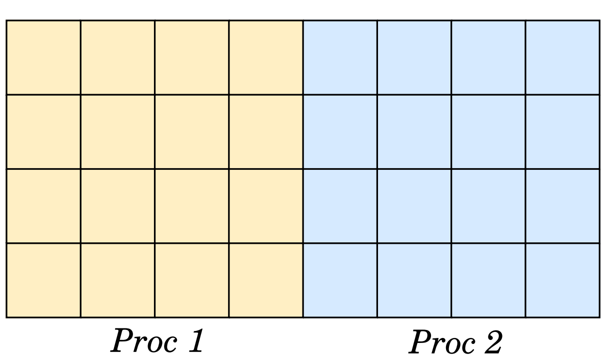

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Grid patterns (continued...)

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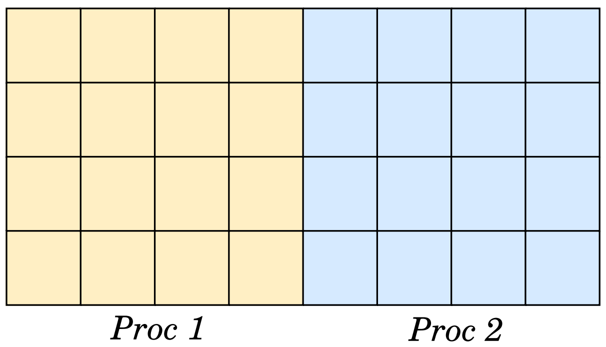
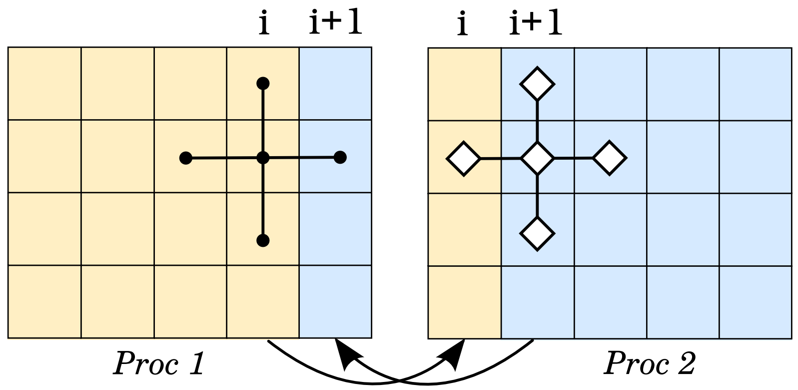


Shared

Distributed



Example: Laplace

```
laplace :: Grid (X*Y) Double -> Double
laplace (X*Y):| _ a  _ | = (a+b+c+d)*0.25
              | b @_ c |
              | _ d  _ |

g = grid <X = 10, Y = 10> data
g' = run laplace (defaults 0.0 g)
```

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- Parameterisable backend for `runPar`

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\begin{array}{rlll}
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\to & b & \textit{initial partial result} \\
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$$\texttt{reduce} :: \text{Reducer}\ a\ b \to \text{Grid}\ D\ a \to b$$

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- Many iterations until convergence

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iterate stencil g r =
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            if (reduce g r) then
               g
            else
               let g' = (run stencil g)
               in iterate stencil g' r
```

Iterating computations (2)

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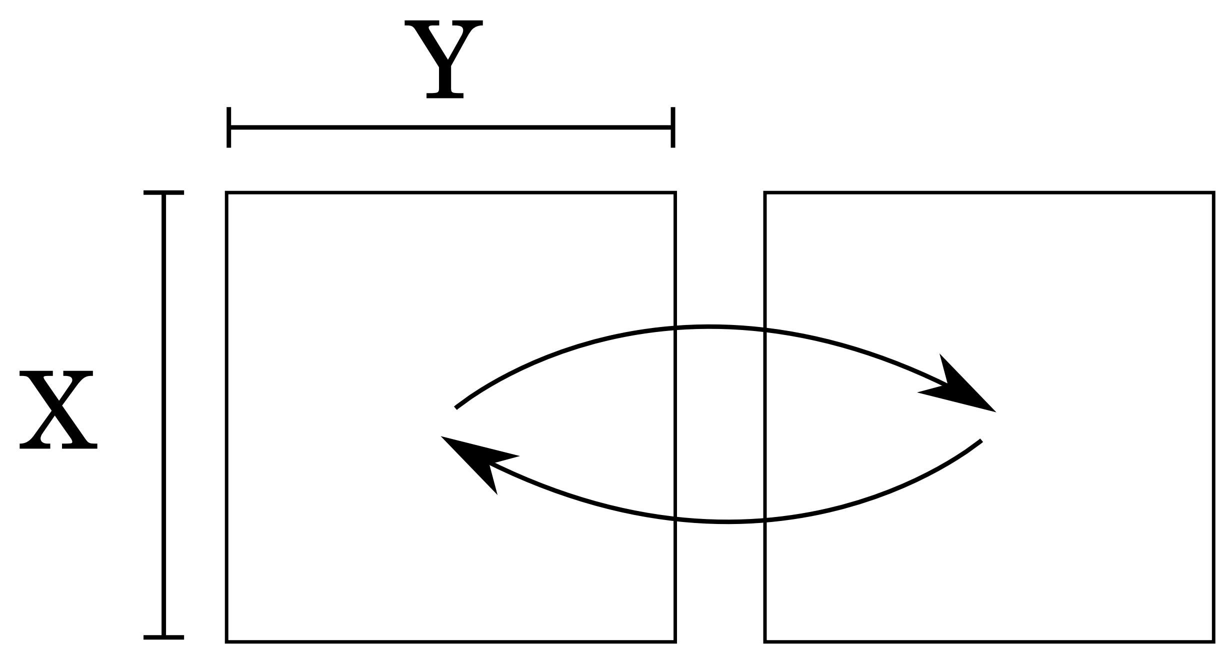

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Creates three intermediate allocations:

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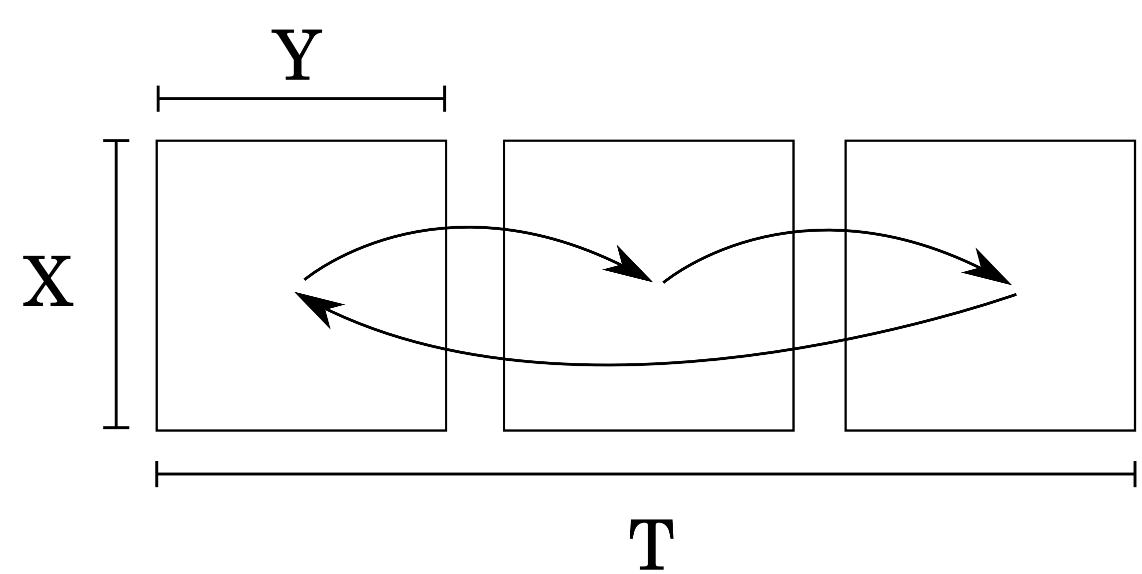

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`iteratePar`   `iterateTPar`

- Parallel versions of `iterate` & `iterateT`
- Locally use optimized destructive update
- Compiler configurations for parameters such as tile size

Summary

$$\texttt{run} :: (\text{Grid}\ d\ a \to b)\ \to\ \text{Grid}\ d\ a\ \to\ \text{Grid}\ d\ b$$

$$\texttt{iterate} :: (\text{Grid}\ d\ a \to a) \to \text{Reducer}\ a\ Bool \to \text{Grid}\ d\ a \to \text{Grid}\ d\ a$$

$$\texttt{iterateT} :: (\text{Grid}\ (T \times d)\ a \to a) \to \text{Reducer}\ a\ Bool \to \text{Grid}\ d\ a \to \text{Grid}\ d\ a$$

and

`runPar, iteratePar, iterateTPar`

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- Tractable cost model for programmer
- **Guaranteed** parallelisation and optimisations
- Easy to write, rewrite, change strategy
- Hardware agnostic. Currently shared & distributed memory backends

Paper

- Orchard D, Bolingbroke M, Mycroft A "*Ypnos: Declarative Parallel Structured Grid Programming*" In proceedings of ACM SIGPLAN DAMP 2010, January, Madrid

Conway's Game of Life

```
life (X*Y):| a b  c | = let local = (a+b+c+d+e+f+g+h+i)
           | d @e f |   in  if (e==1) then
           | g h  i |         if (local<2 || local>3)
                               then 0 else 1
                             else
                               if (local==3)
                               then 1 else 0
-- Create environment
initalState = grid <X=10, Y=10> randomConfiguration

untilMostlyDead = Reducer (+) (+) 0.0 (\x -> (x<10))
stopCondition = (untilMostlyDead `orReducer` (ntimes 100))

intialState' = defaults 0.0 initialState
finalState = iterate life stopCondition initialState'
```