Why Structured Parallel Programming Matters

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Scotland's sunshine capital!

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Programming is by careful selection and combination of operations drawn from a small, simple set.

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It is very difficult for implementation mechanisms (working statically and/or dynamically) to attempt optimisations which work beyond single instances of the primitives.

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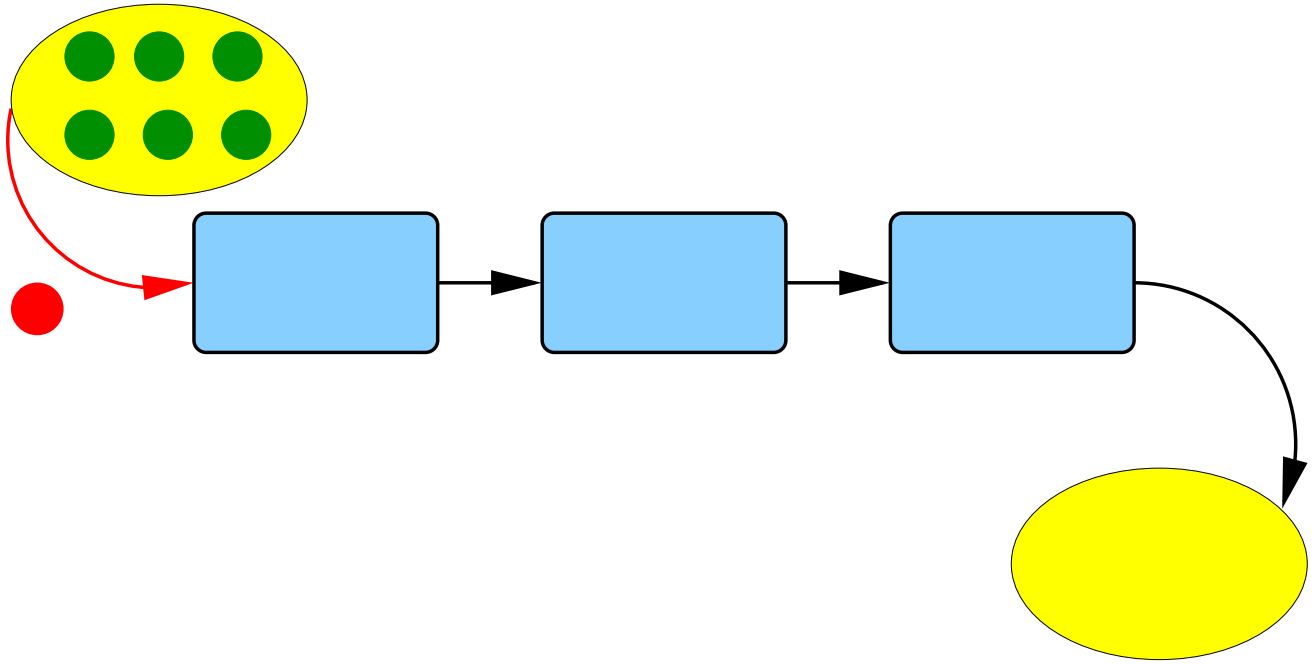

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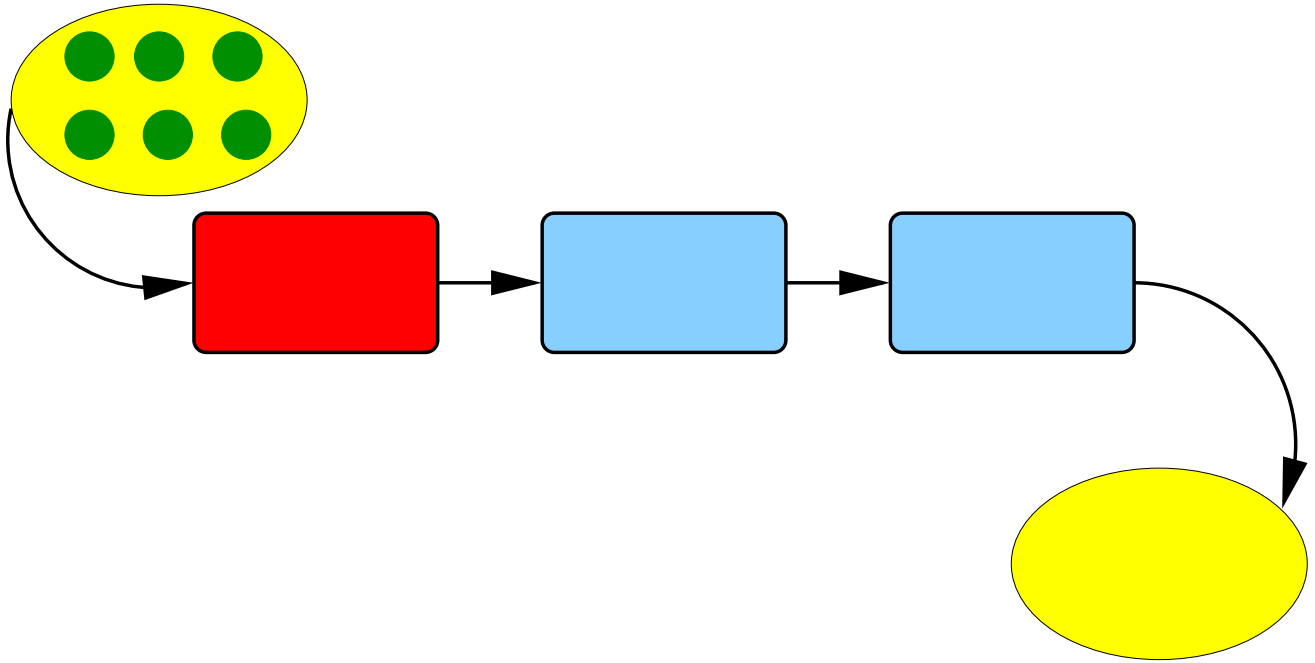

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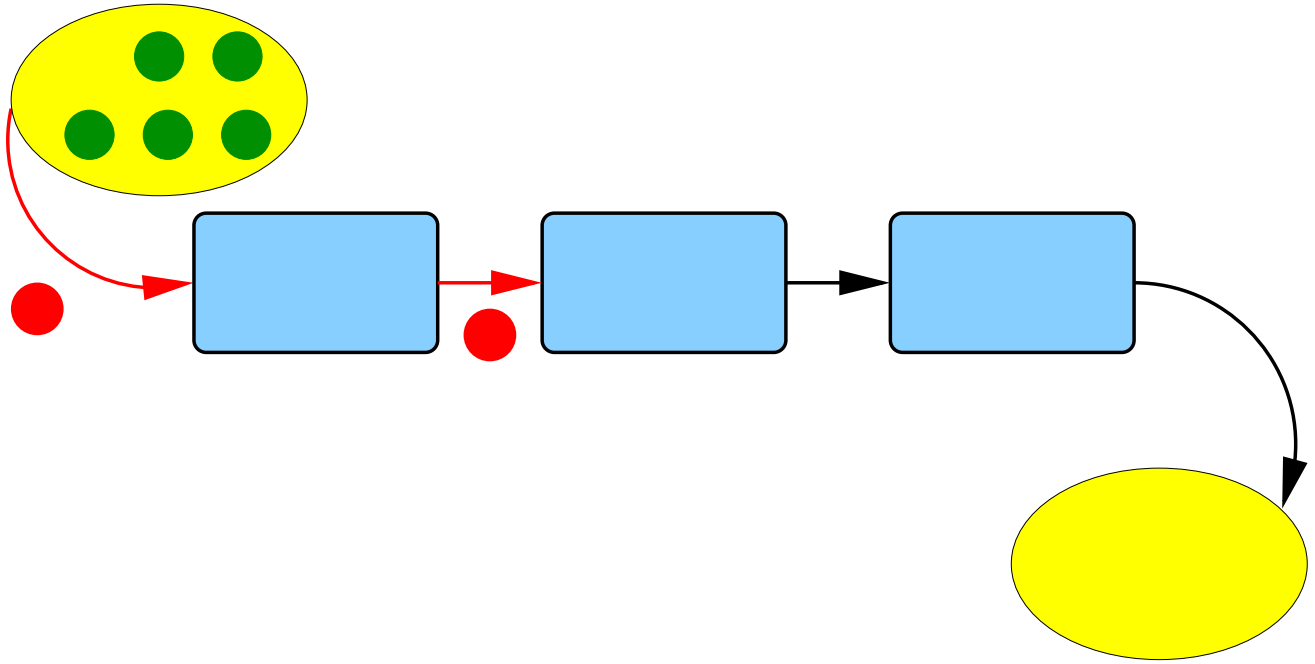

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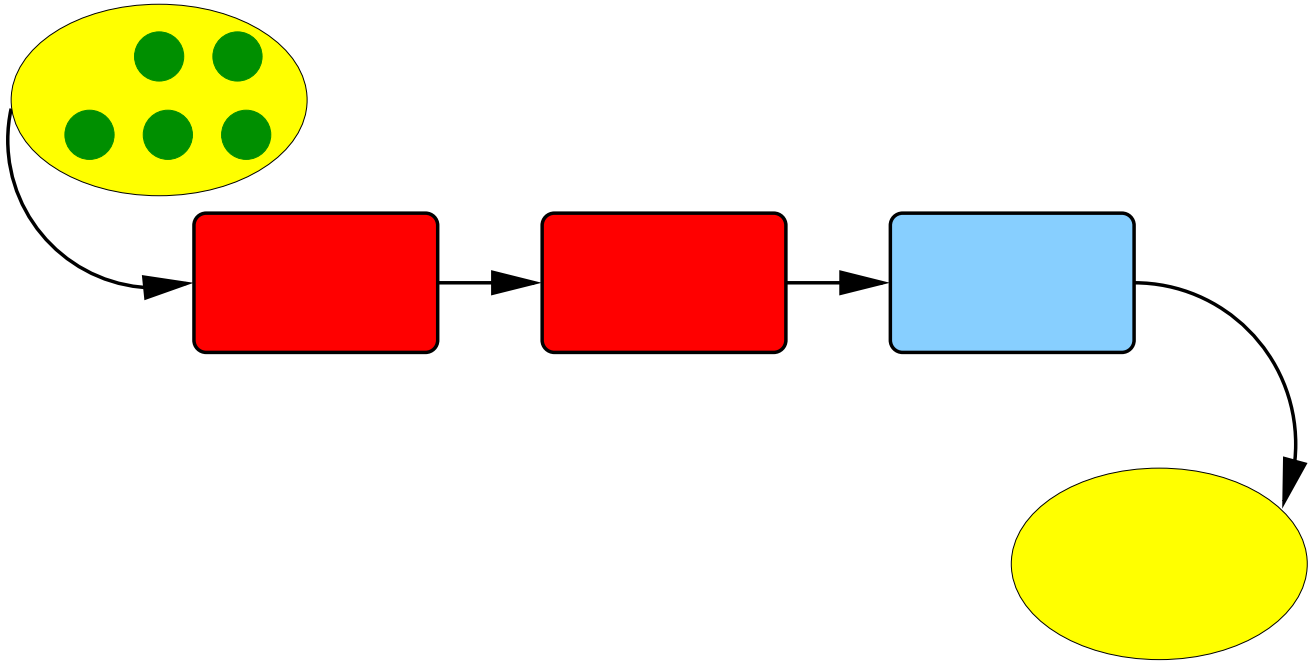

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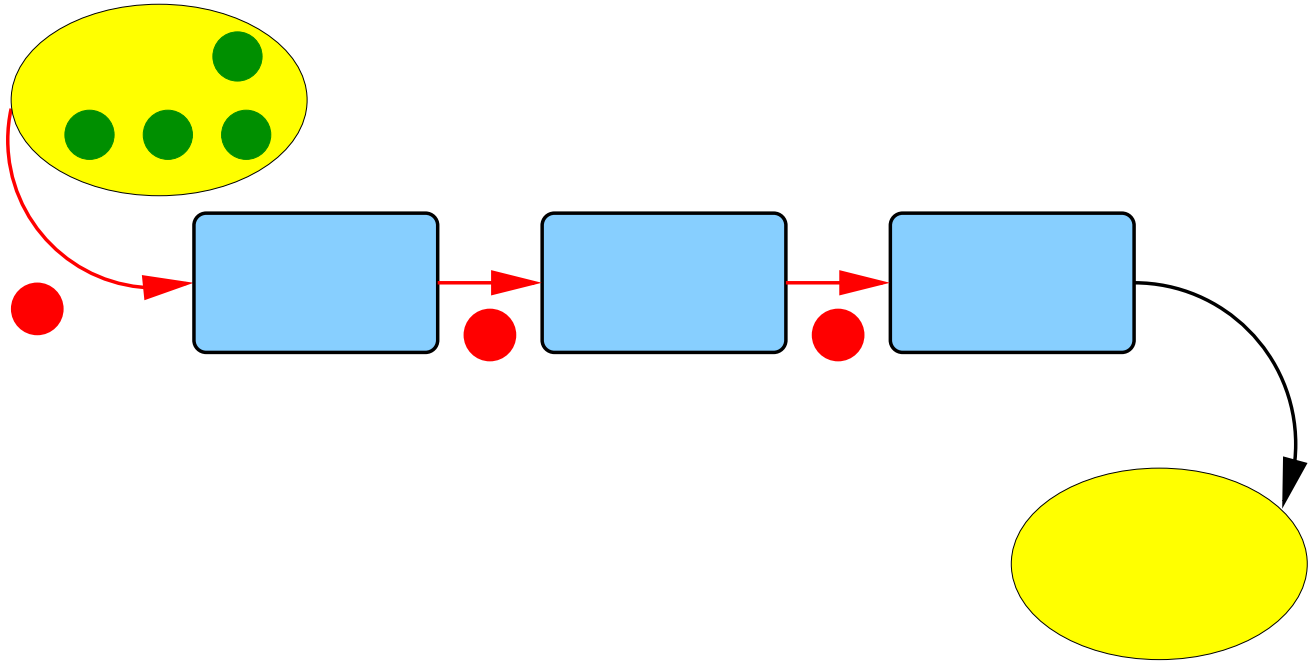

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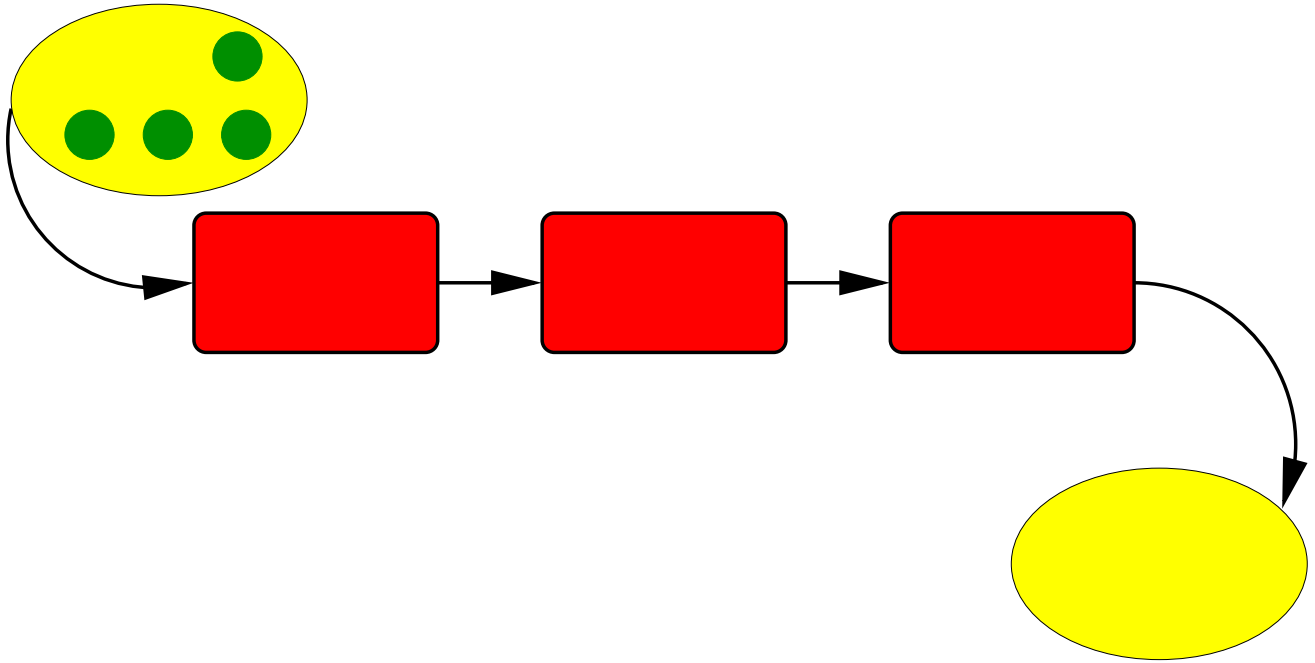

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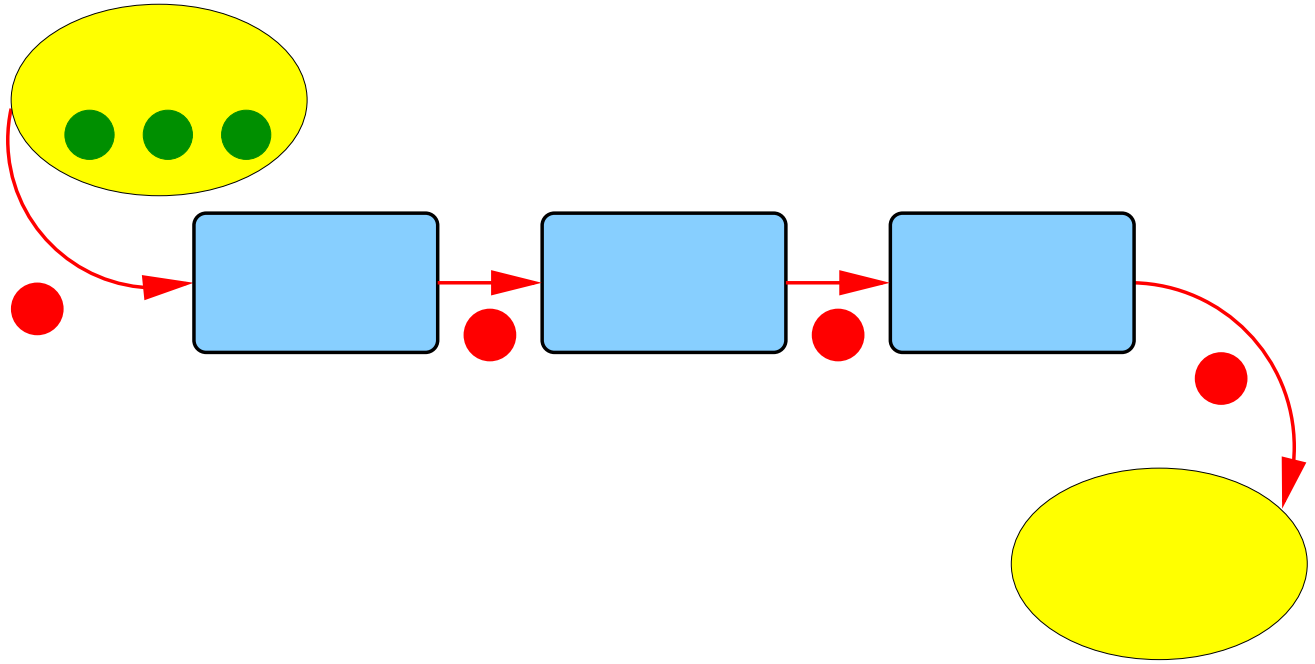

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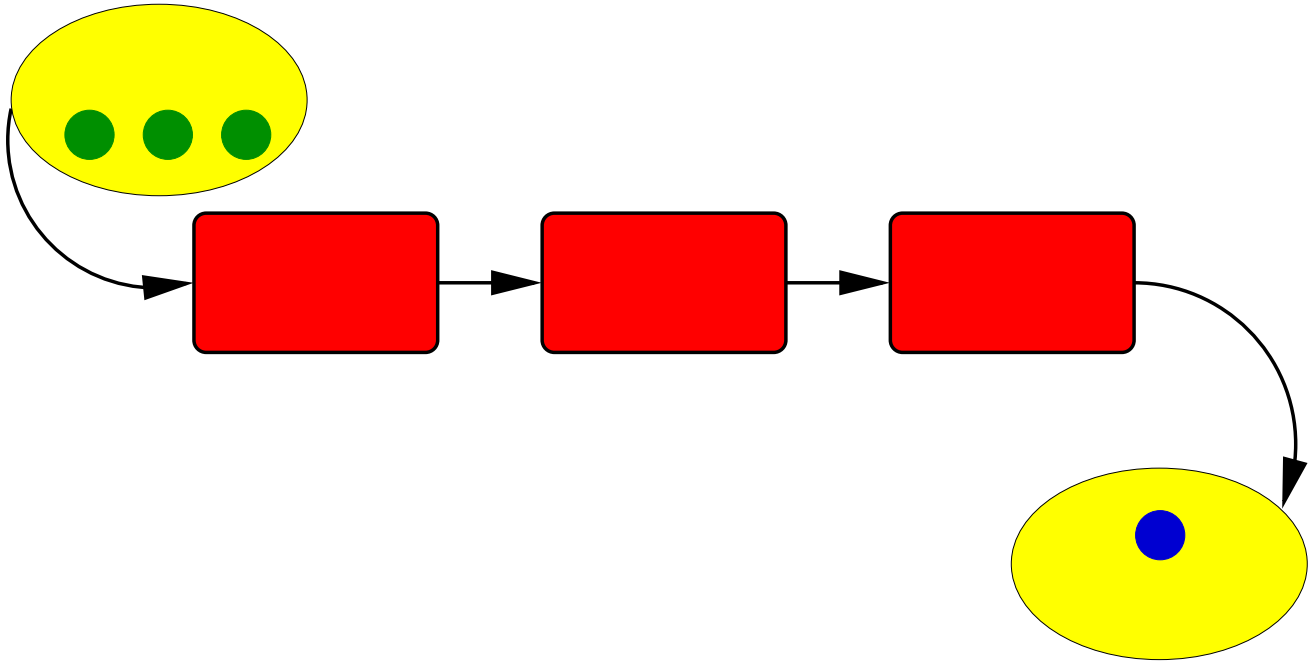

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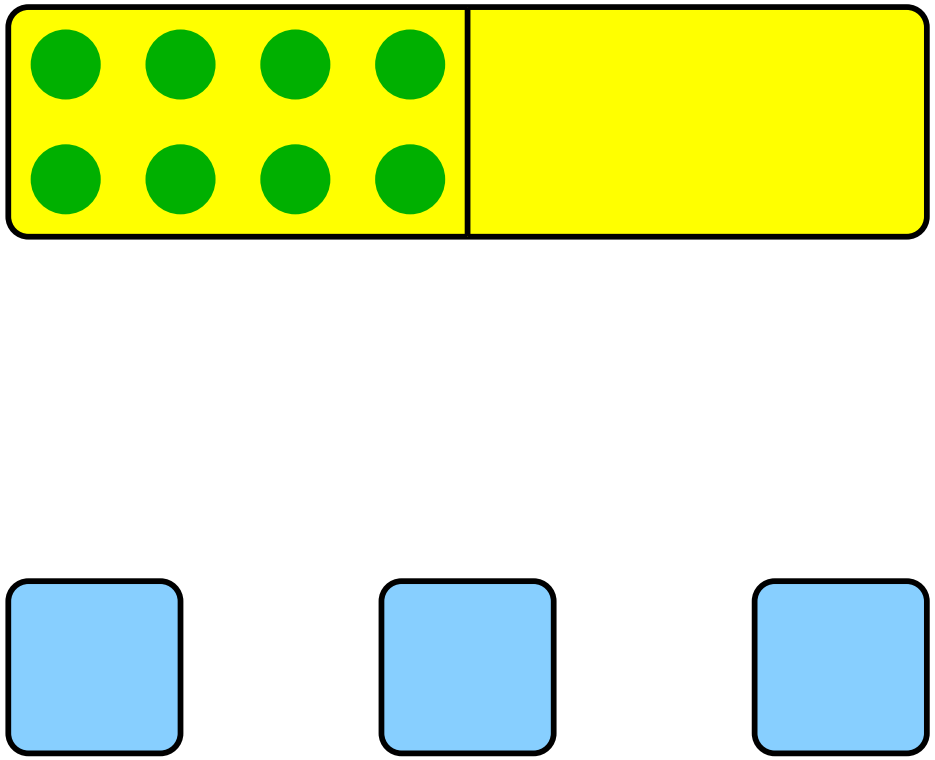

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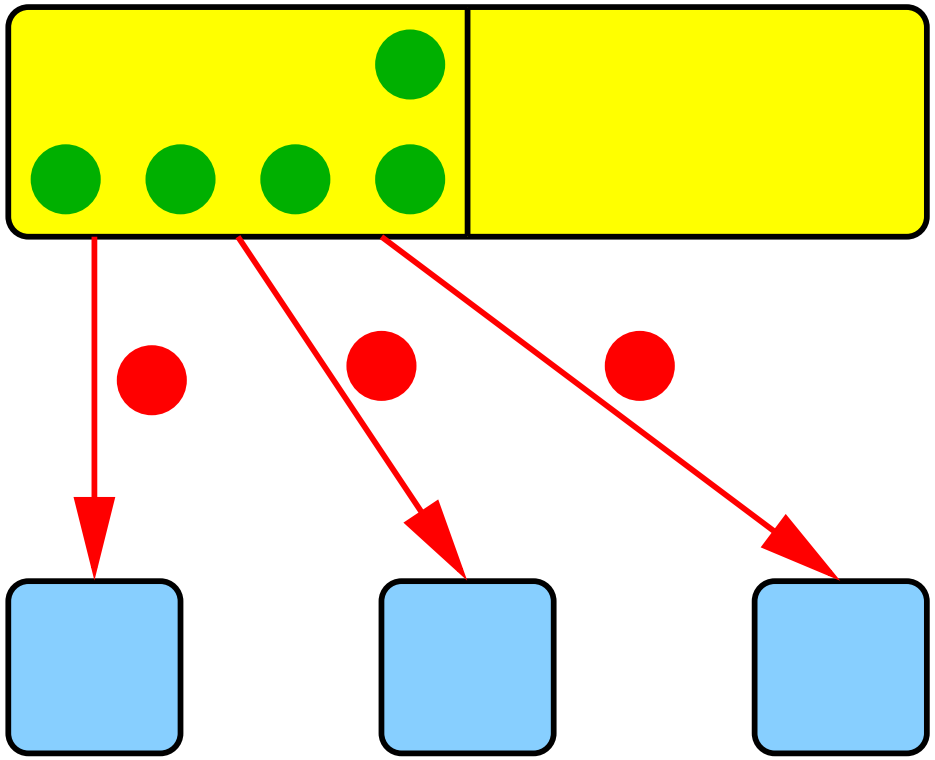

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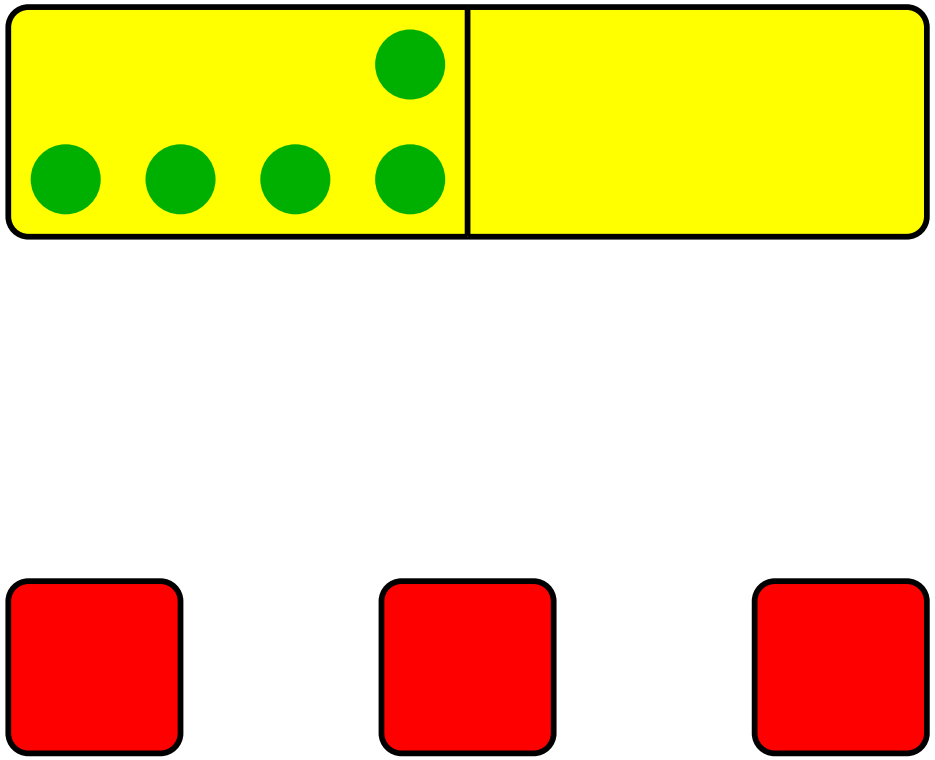

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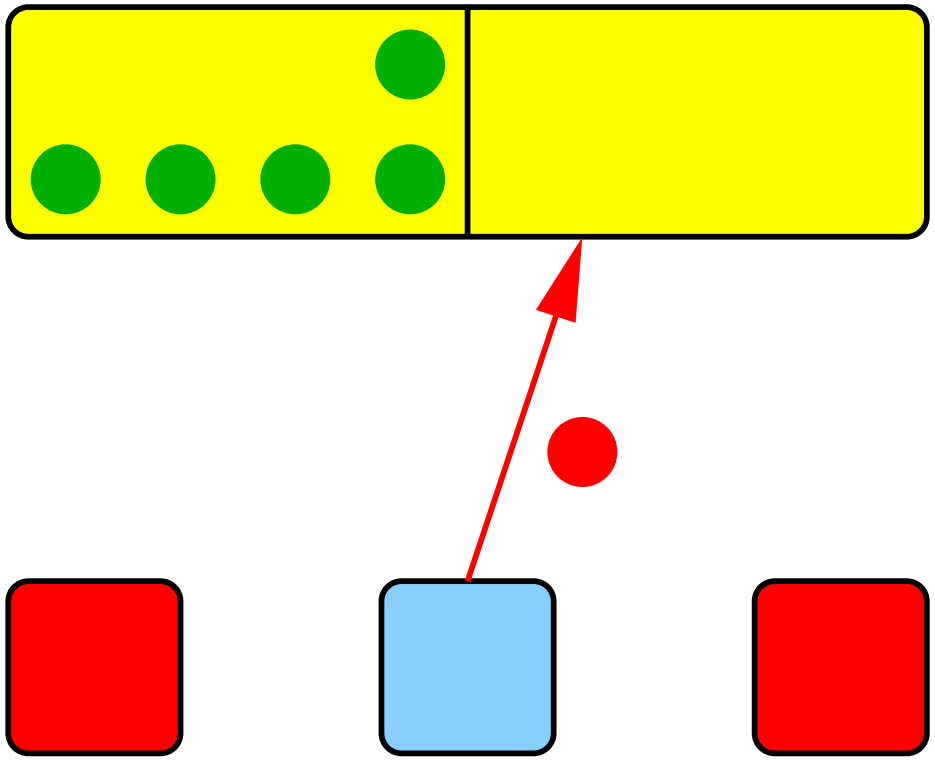

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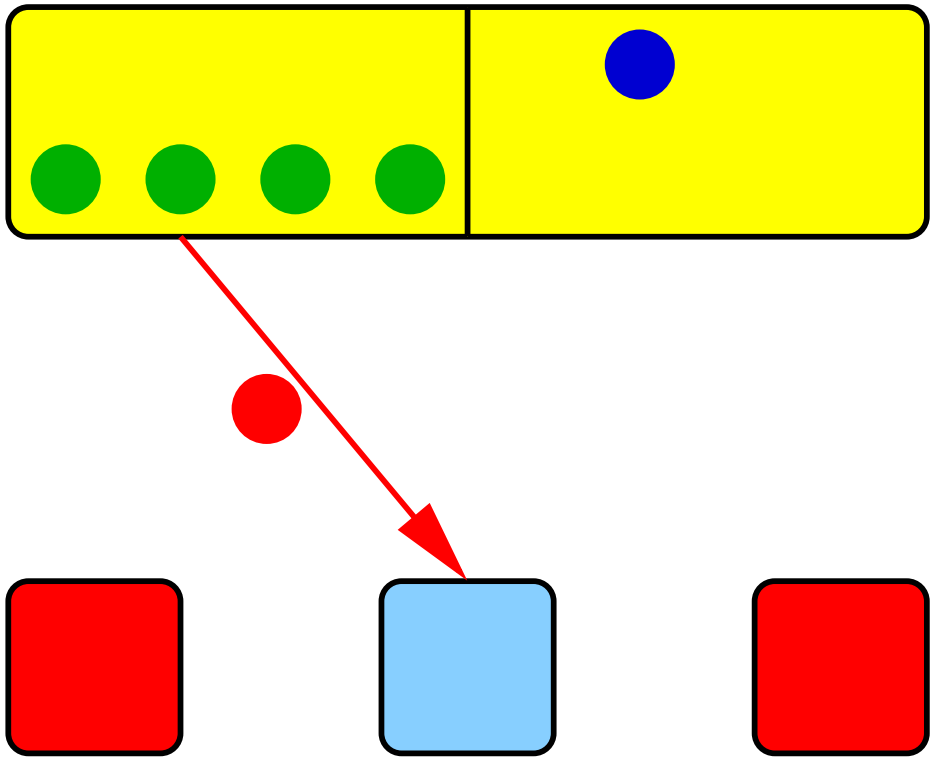

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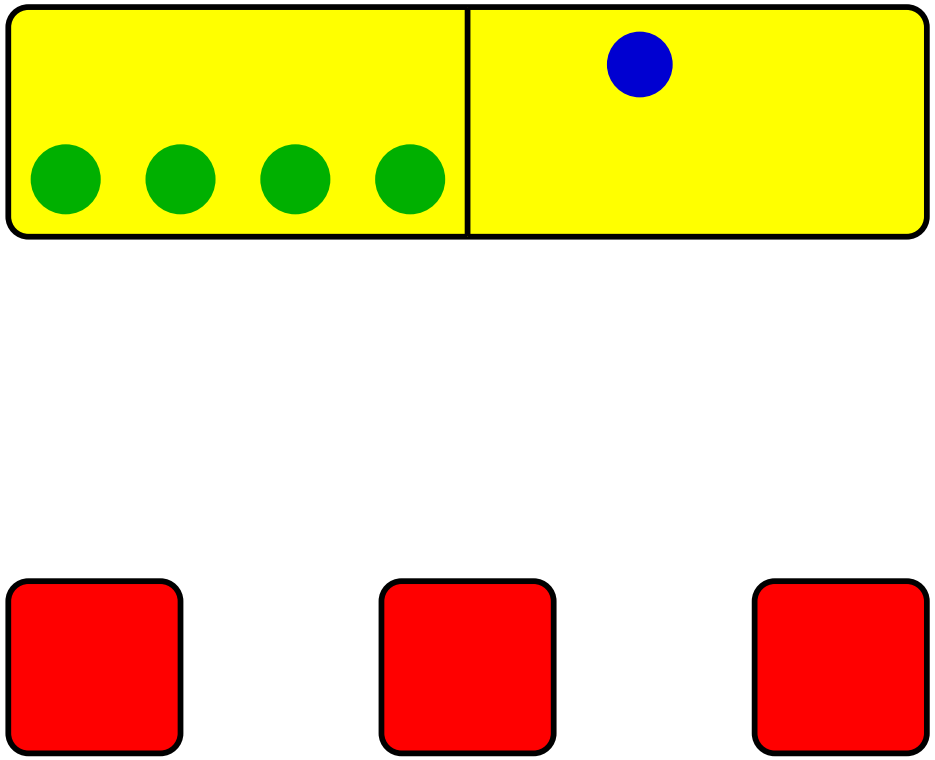

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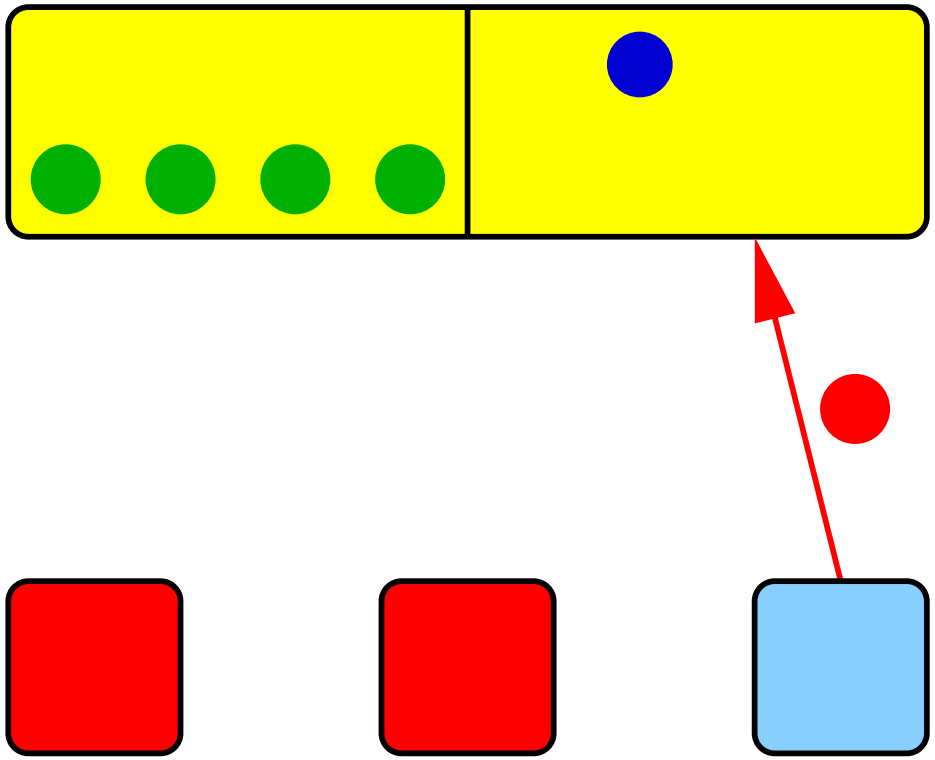

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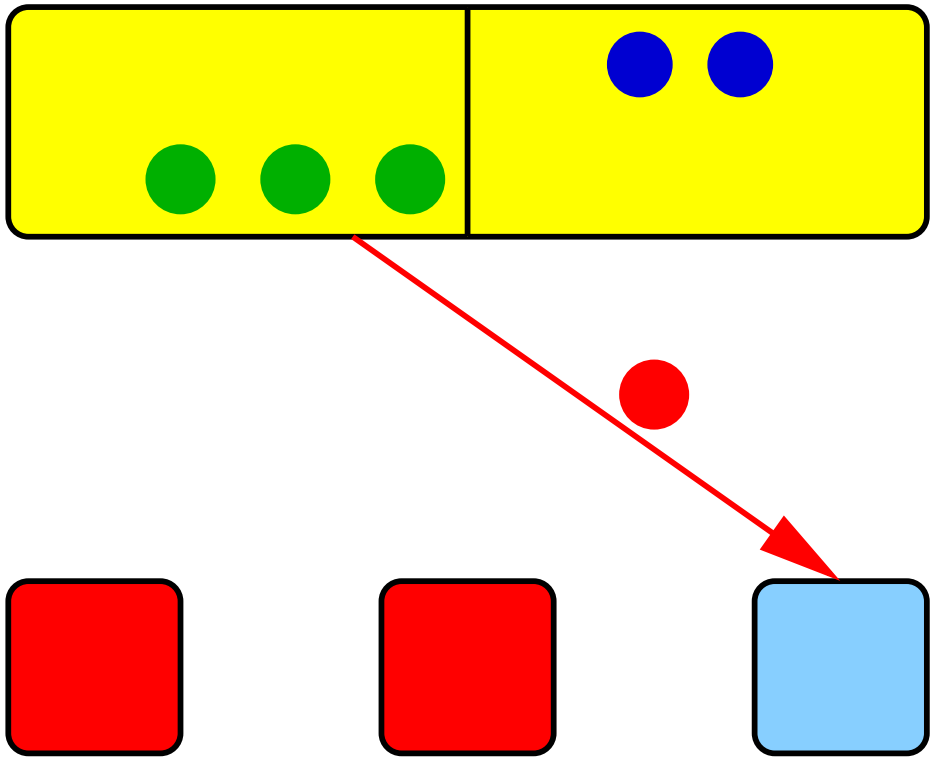

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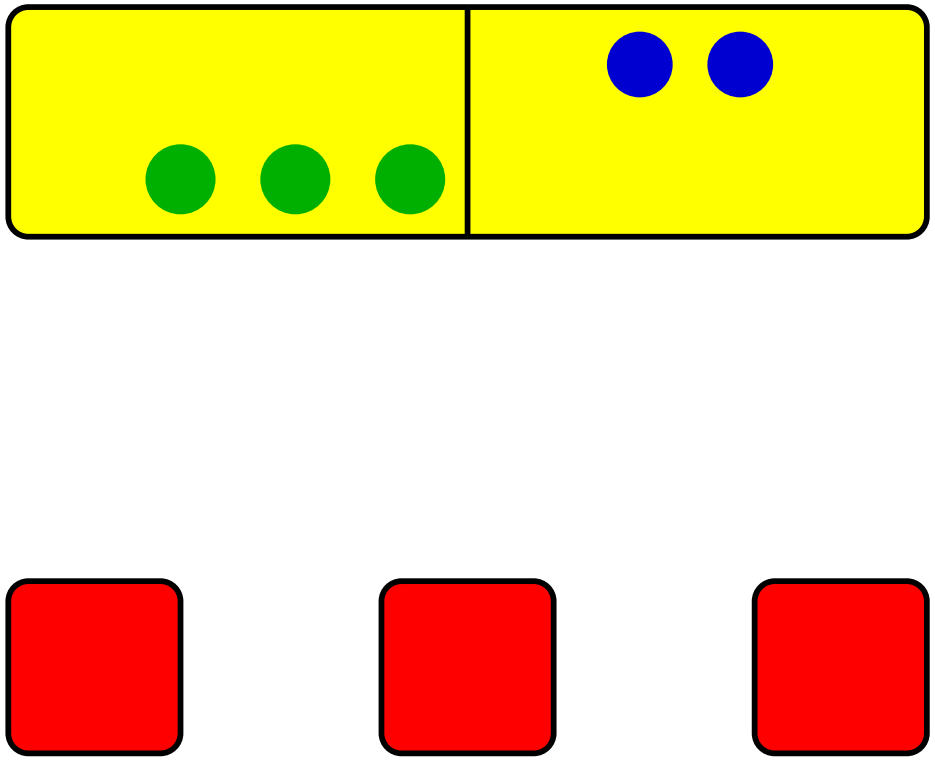

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The use of an unstructured parallel programming mechanism prevents the programmer from expressing information about the pattern - it remains implicit in the collected uses of the simple primitives.

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This matters because it gives a tractable handle on the issues which make correct, efficient parallel programming hard.

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Yes. The pattern abstracted by the skeleton hides all the interaction.

How Performance Optimisations Work

Well known, tried and trusted performance optimisations typically exploit information about the spatial and temporal context in which indvidual operations are performed.

Cache Optimisations

```
for (i=0;i<N;i++)
   for (j=0;j<N;j++)
       for (k=0; k<N; k++)
           c[i][j] += a[i][k]*b[k][j];
```

Cache Optimisations

```
for (jj=0; jj<N; jj=jj+B)
   for (kk=0; kk<N; kk=kk+B)
      for (i=0; i<N; i++)
         for (j=jj; j < jj+B; j++) {
            pa = &a[i][kk]; pb = &b[kk][j];
            temp = (*pa++)*(*pb);
            for (k=kk+1; k < kk+B; k++) {
              pb = pb+N;
              temp += (*pa++)*(*pb);
            }
            c[i][j] += temp;
      }
```

Branch Prediction

```
while (a[i] < b[a[i]]) {
    c[j+i] += b[j];
    if (c[k] < 100) {
        k++;
        b[j] = 0;
    }
    i++;
}
```

Performance improved by knowing whether branches are "usually" taken.

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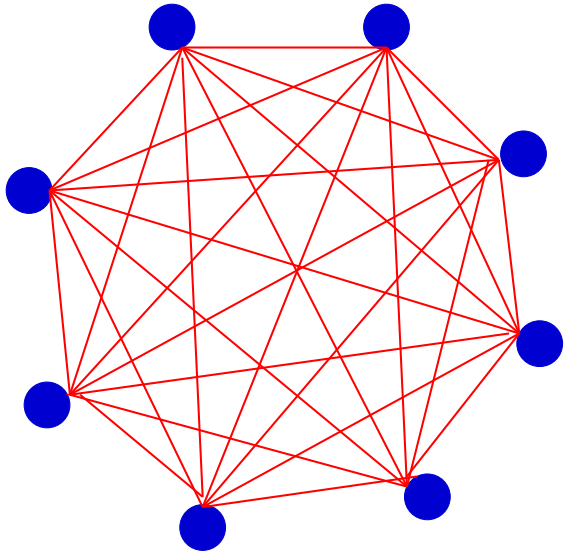
Structured Parallelism lets us tell the system what will happen next.

Parallel Performance Optimisations

Consider a simple "iterated all-pairs" structure



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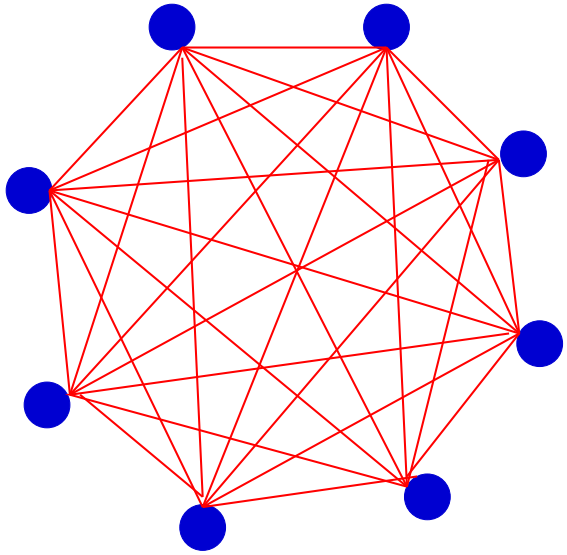
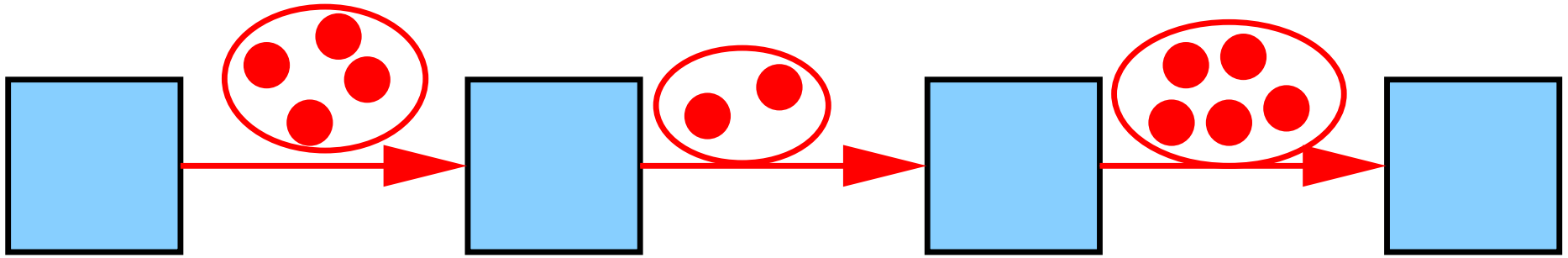


Careful shared memory scheduling is essential.

Parallel Performance Optimisations

In a simple pipeline, agglomeration of messages can be crucial.



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Structured Parallelism matters because it allows us to give the system this information (and as a side-effect, simplifies our programming task).

Higher Level Performance Optimisation

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The coarse grain, collective nature of skeletons allows substantial transformations to be made with a small number of steps (in contrast to the same effect achieved with the corresponding unstructured primitives).

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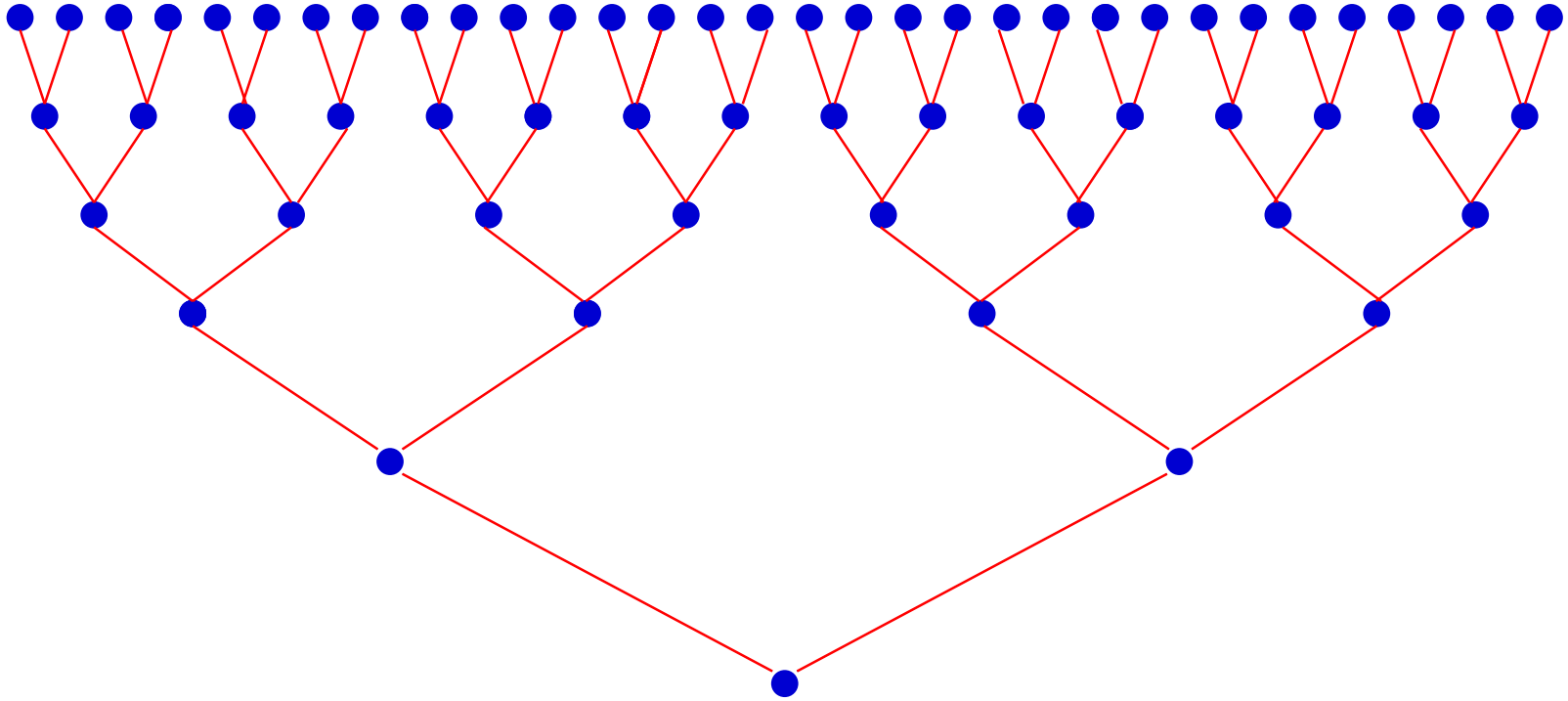

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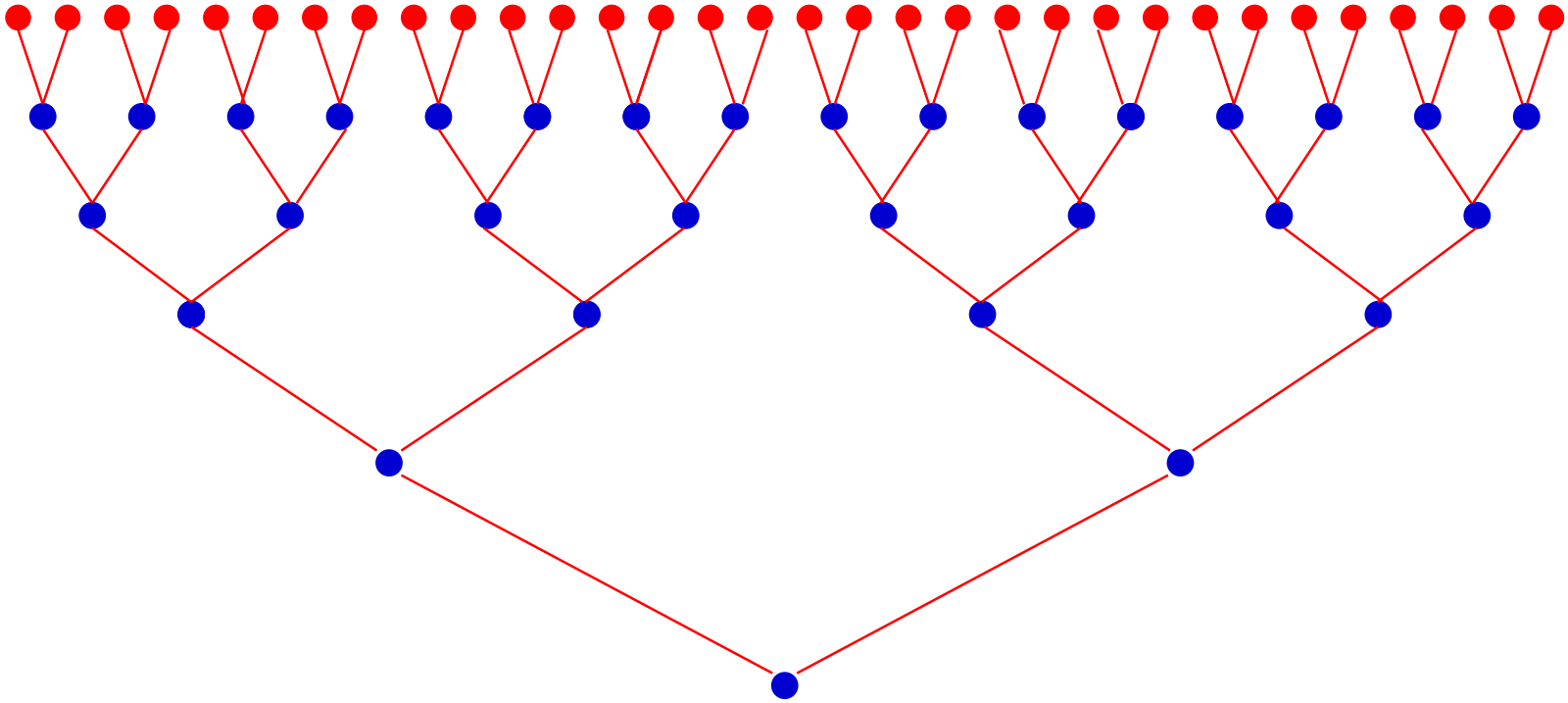

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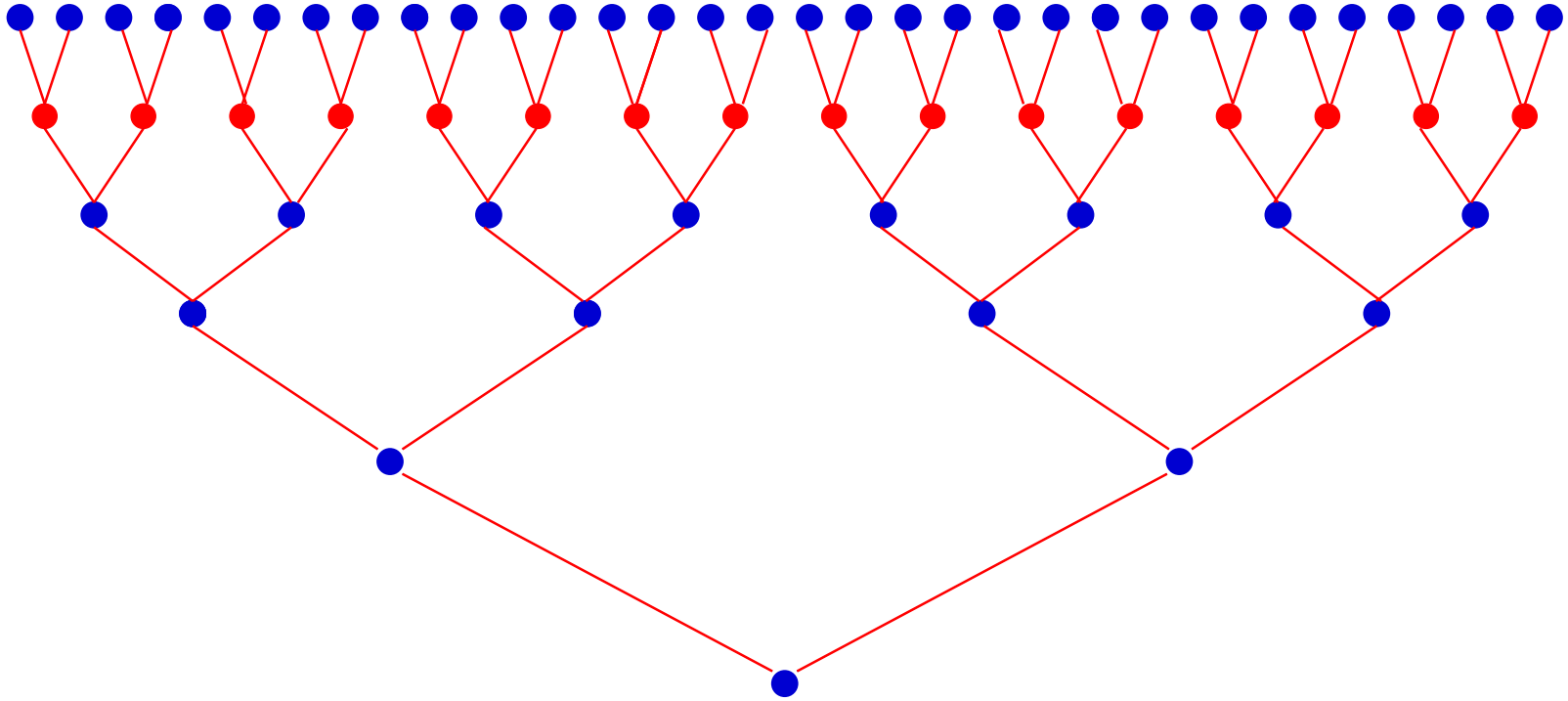

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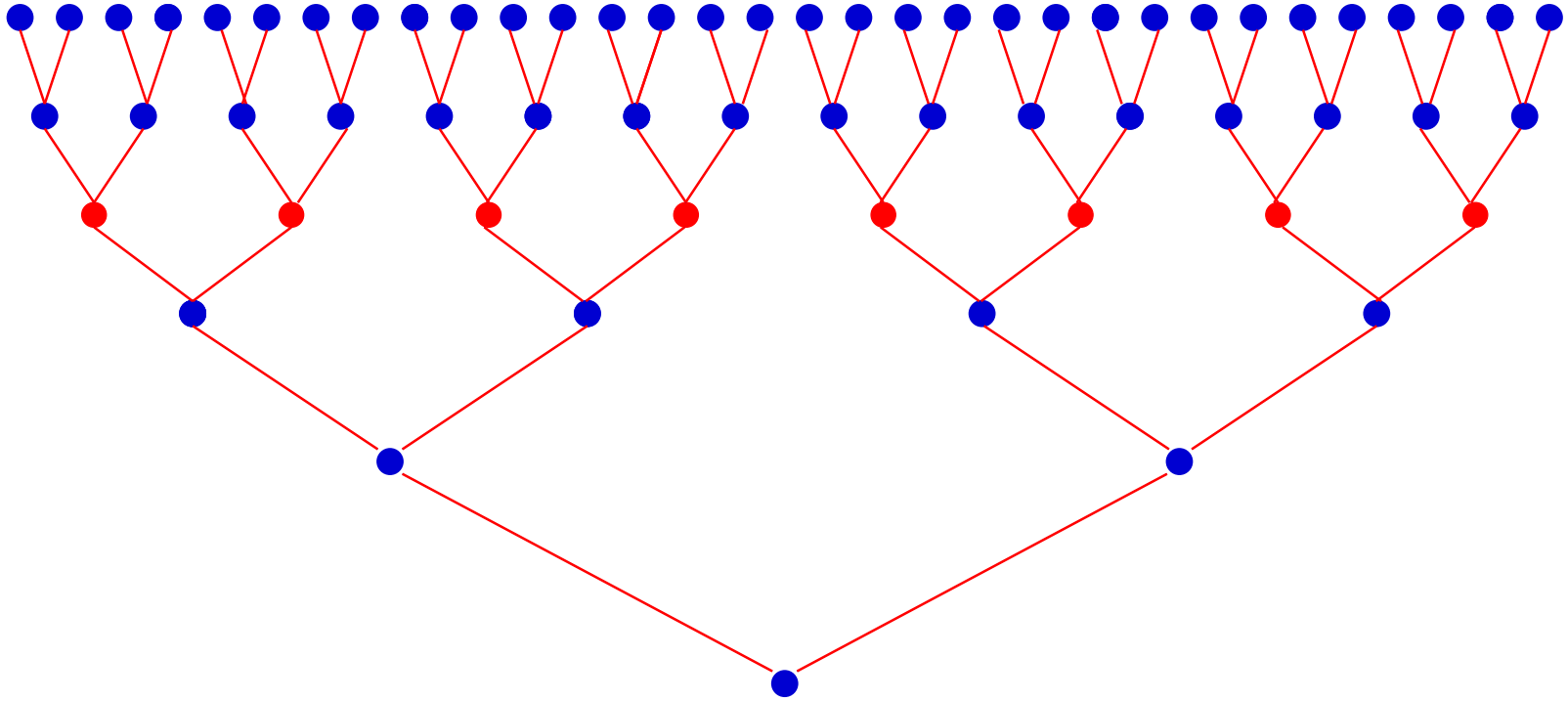

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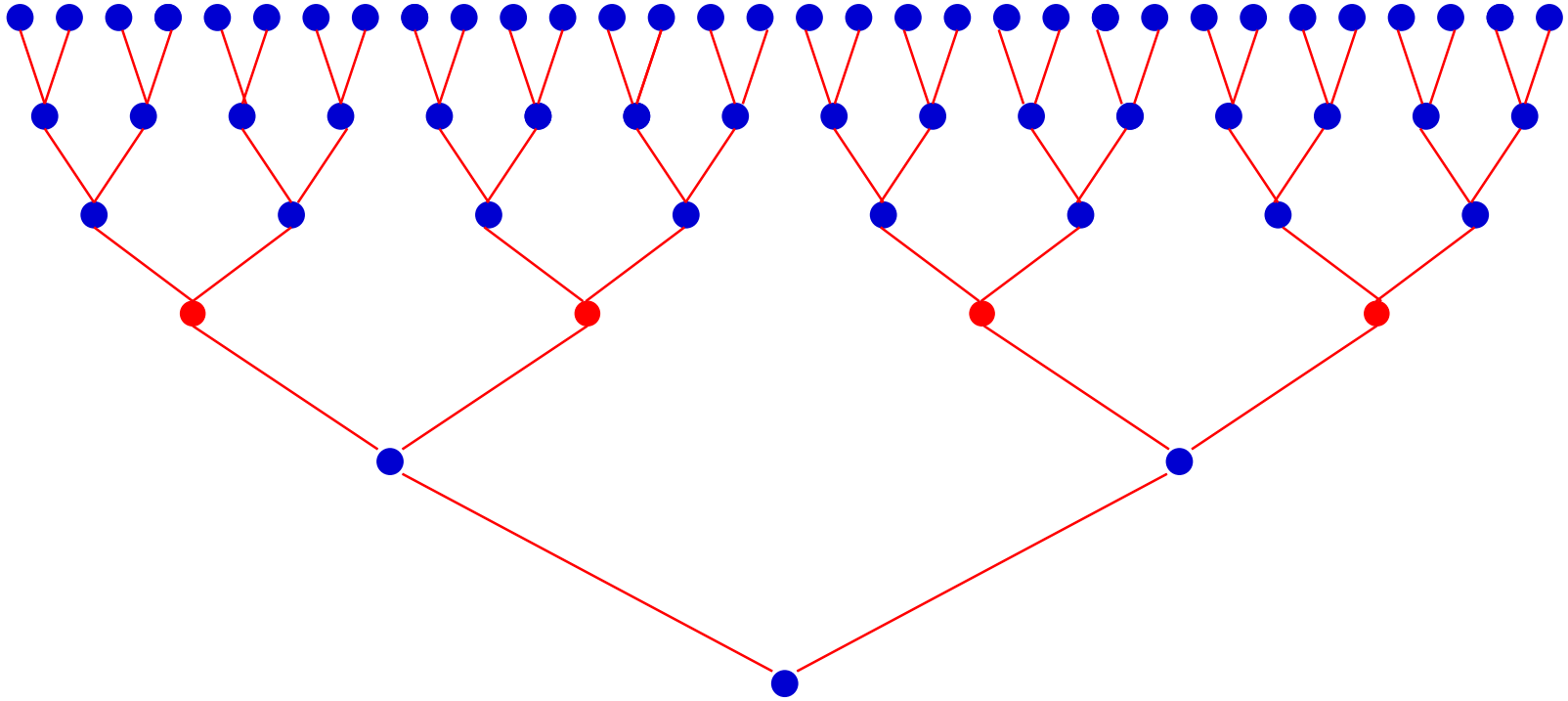

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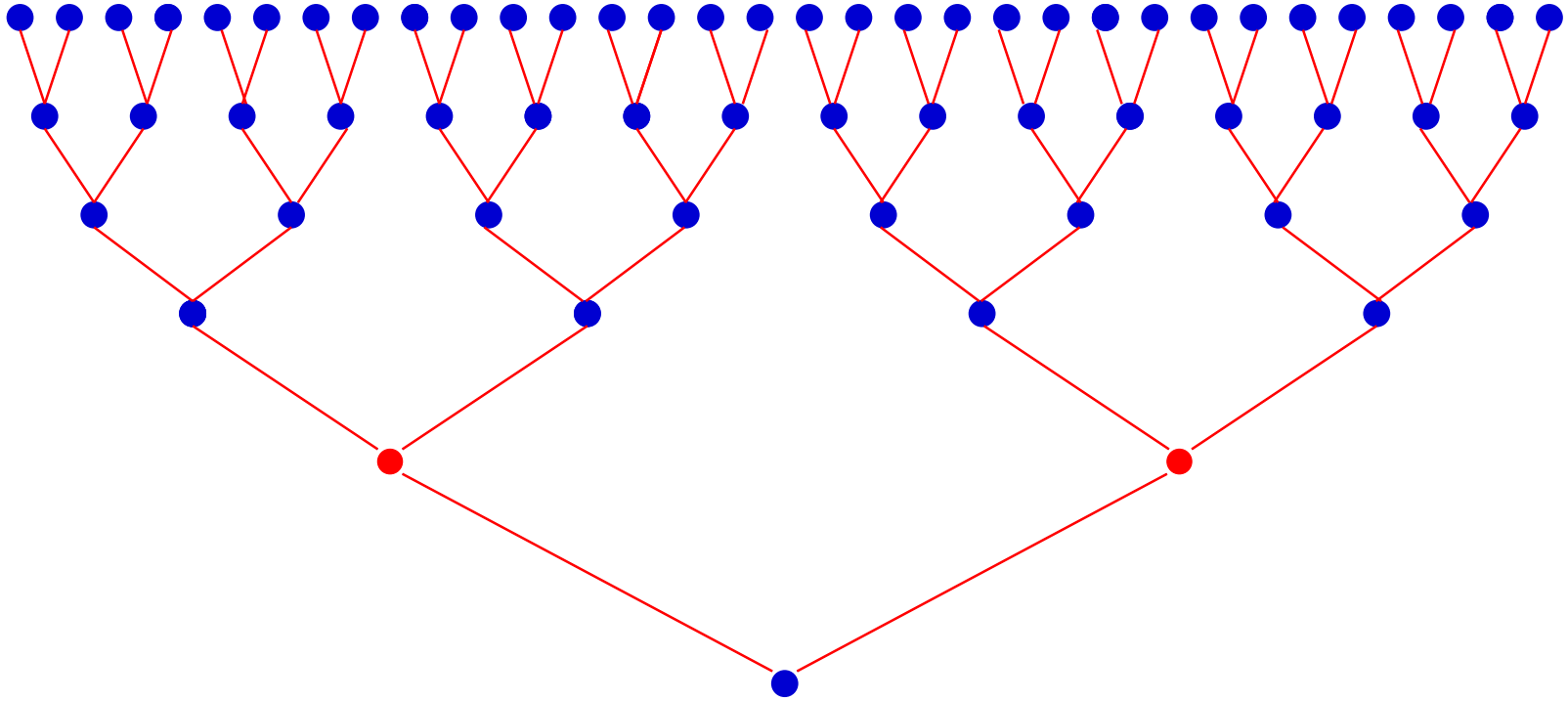

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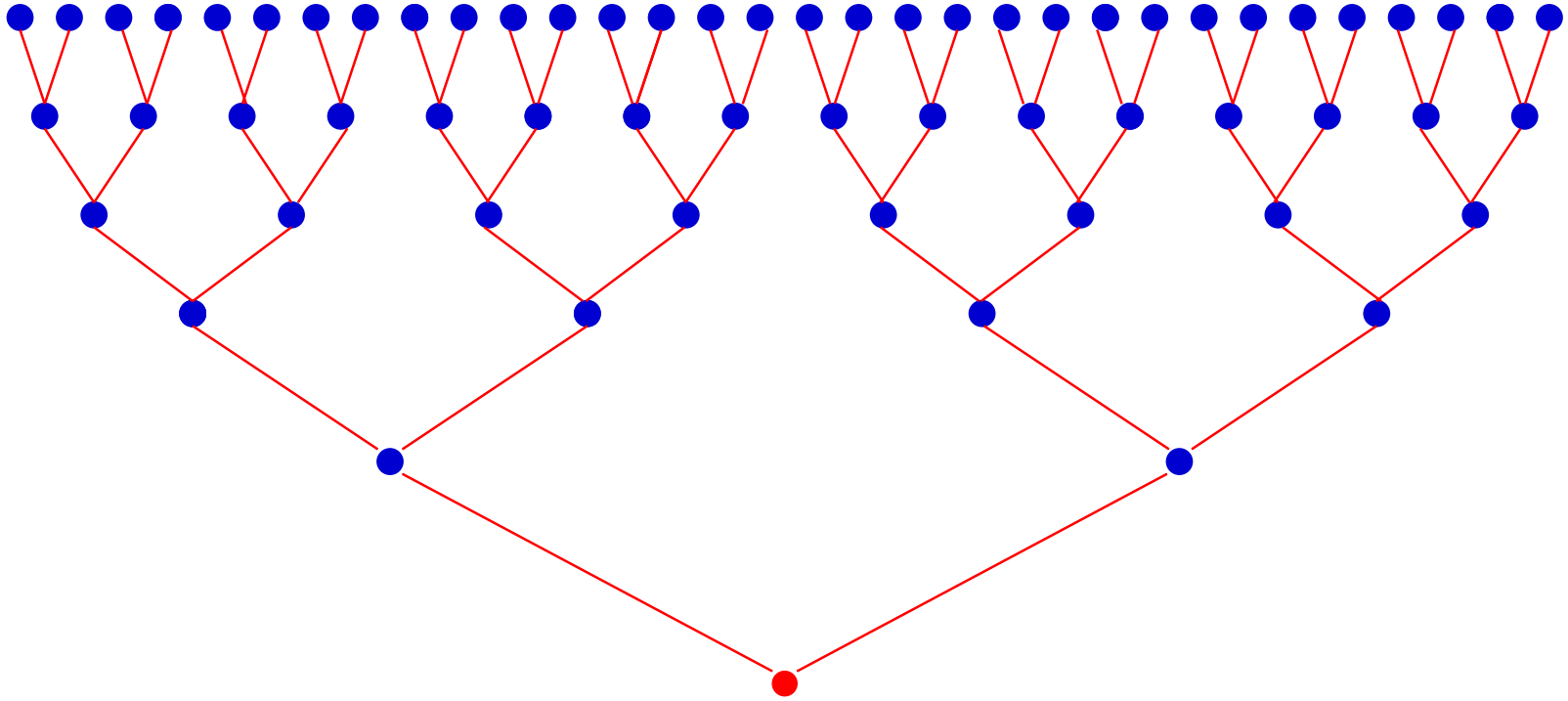

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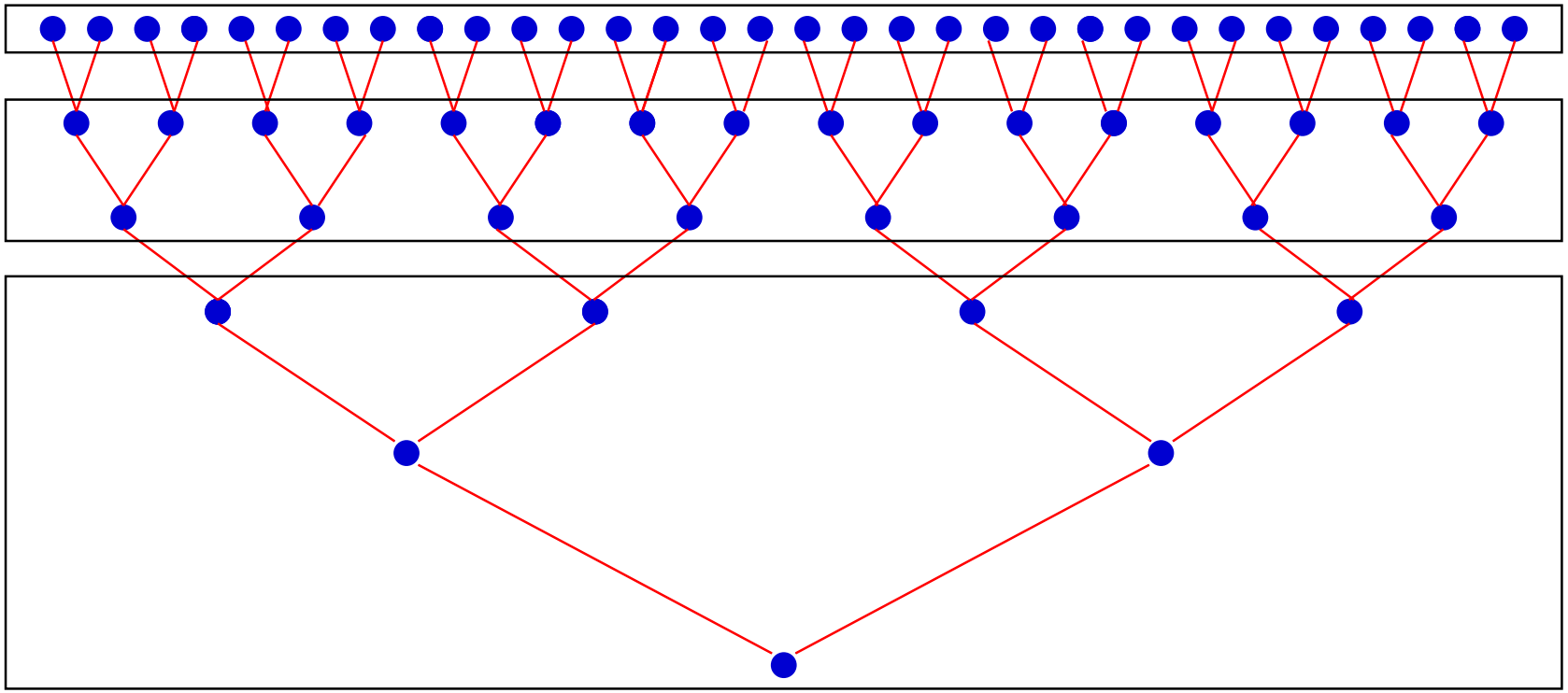

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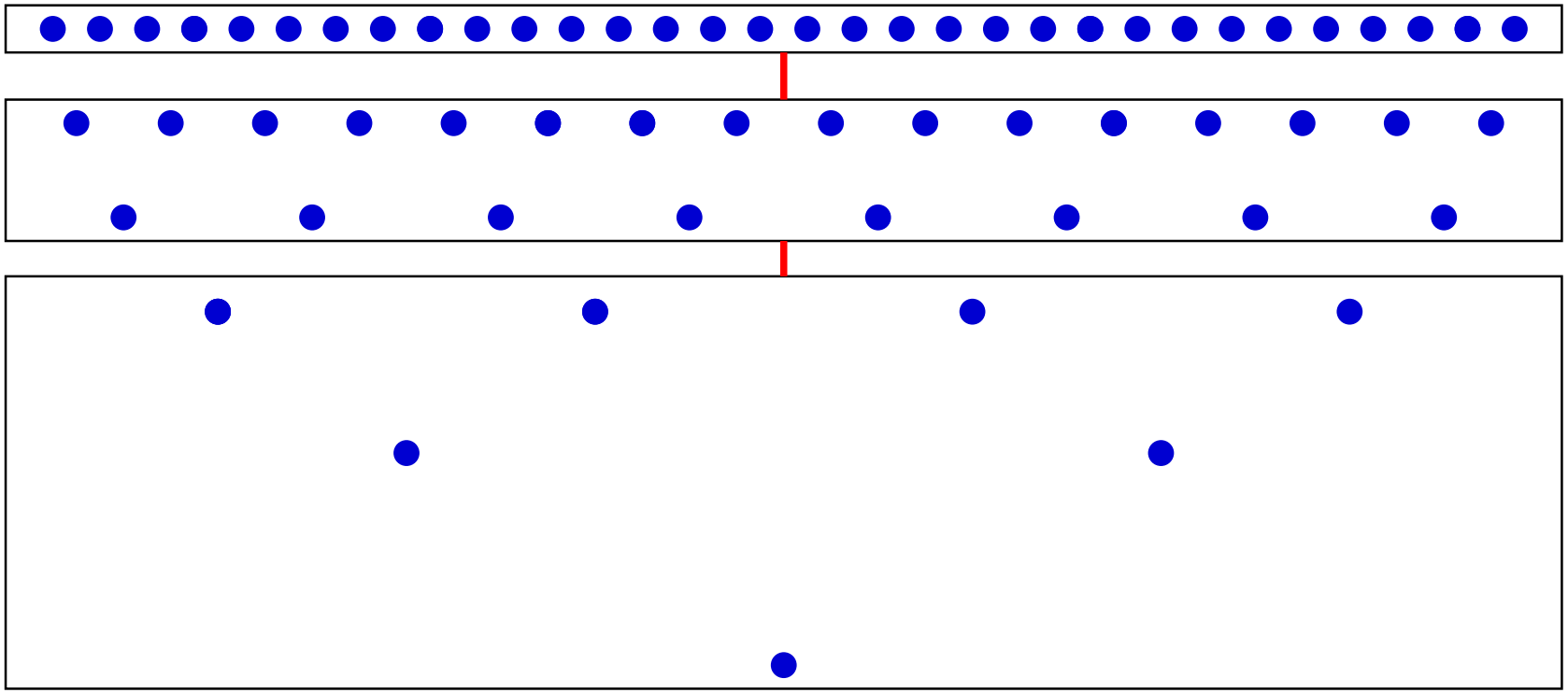

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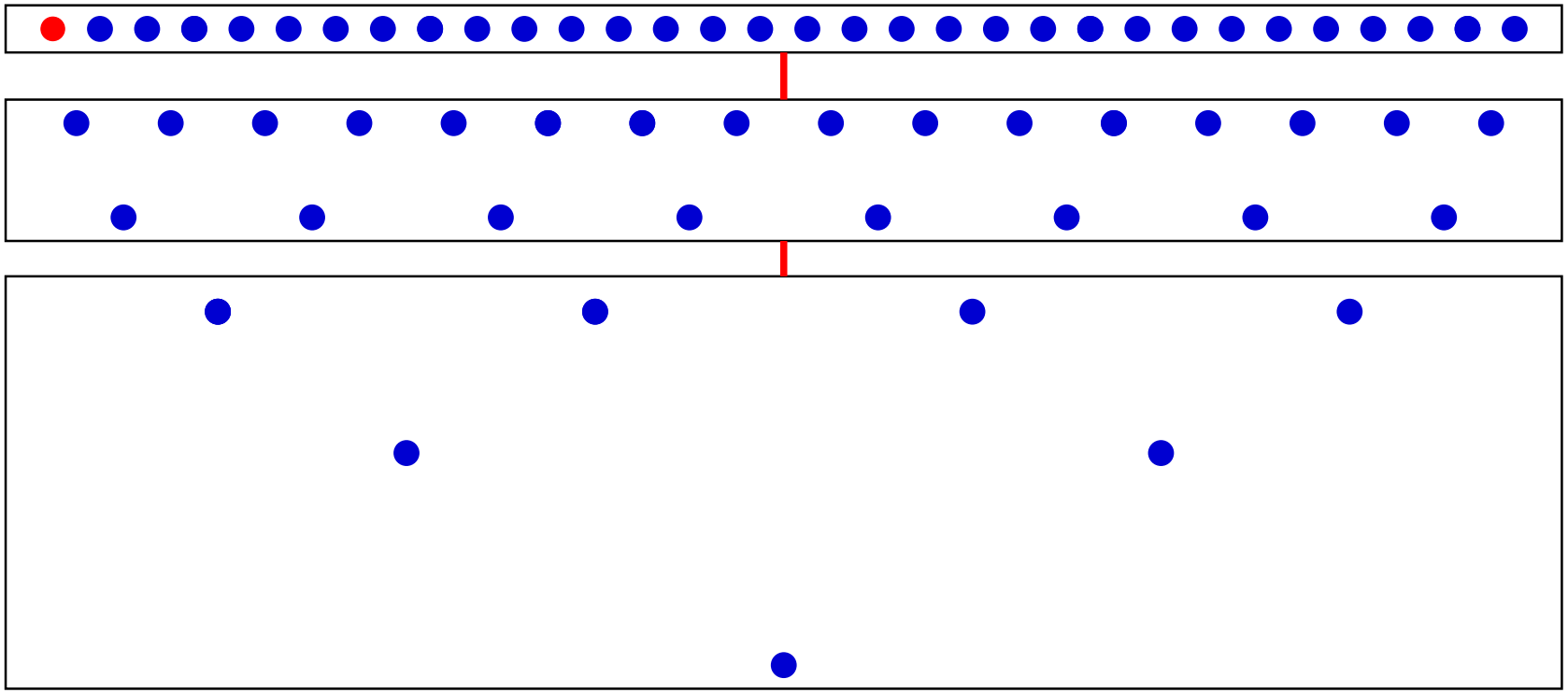

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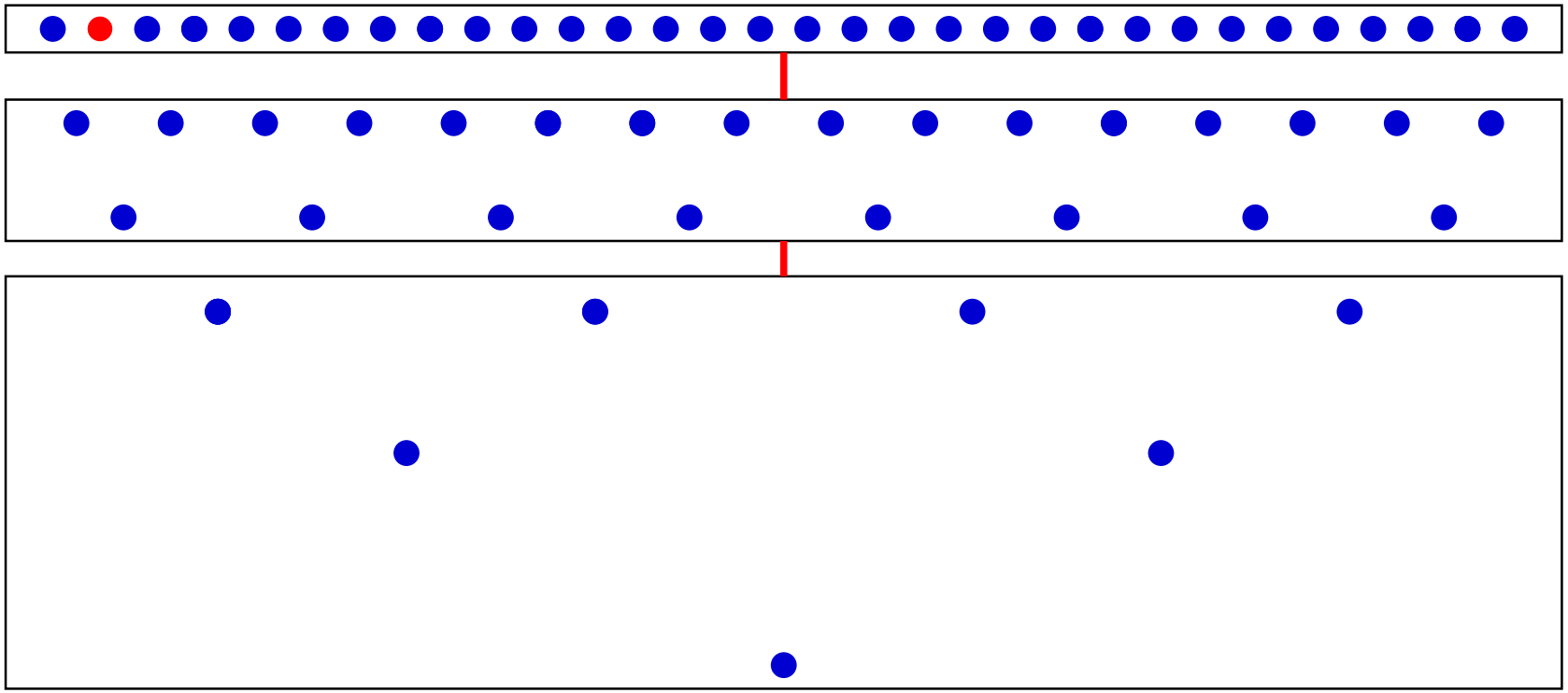

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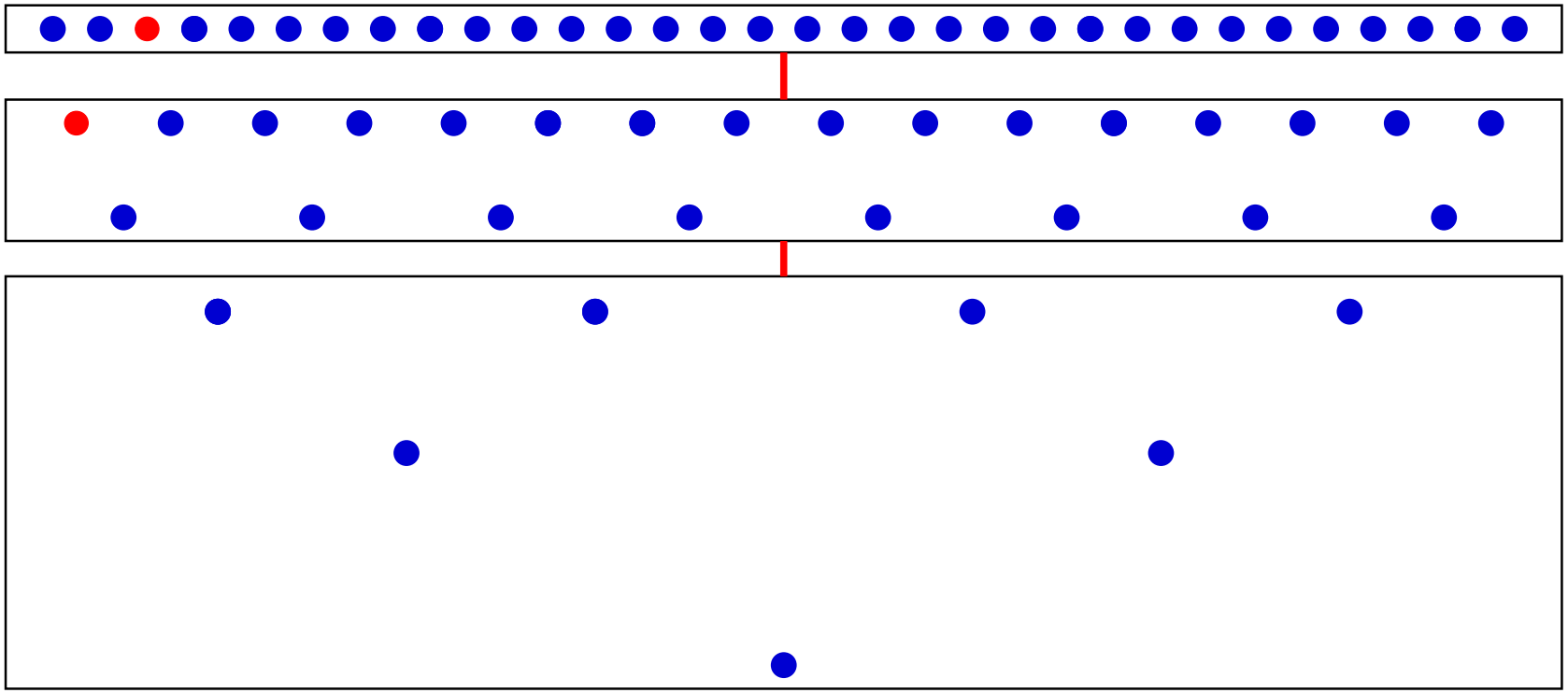

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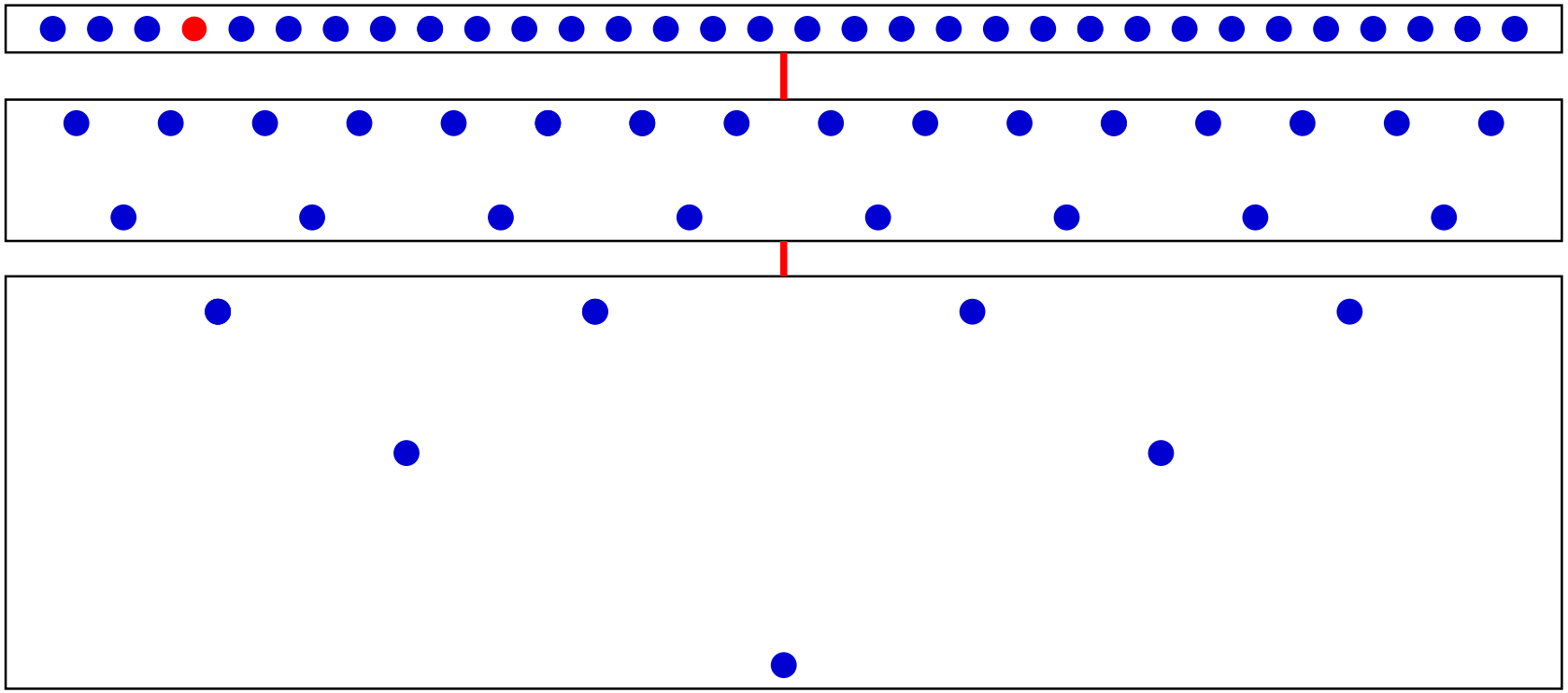

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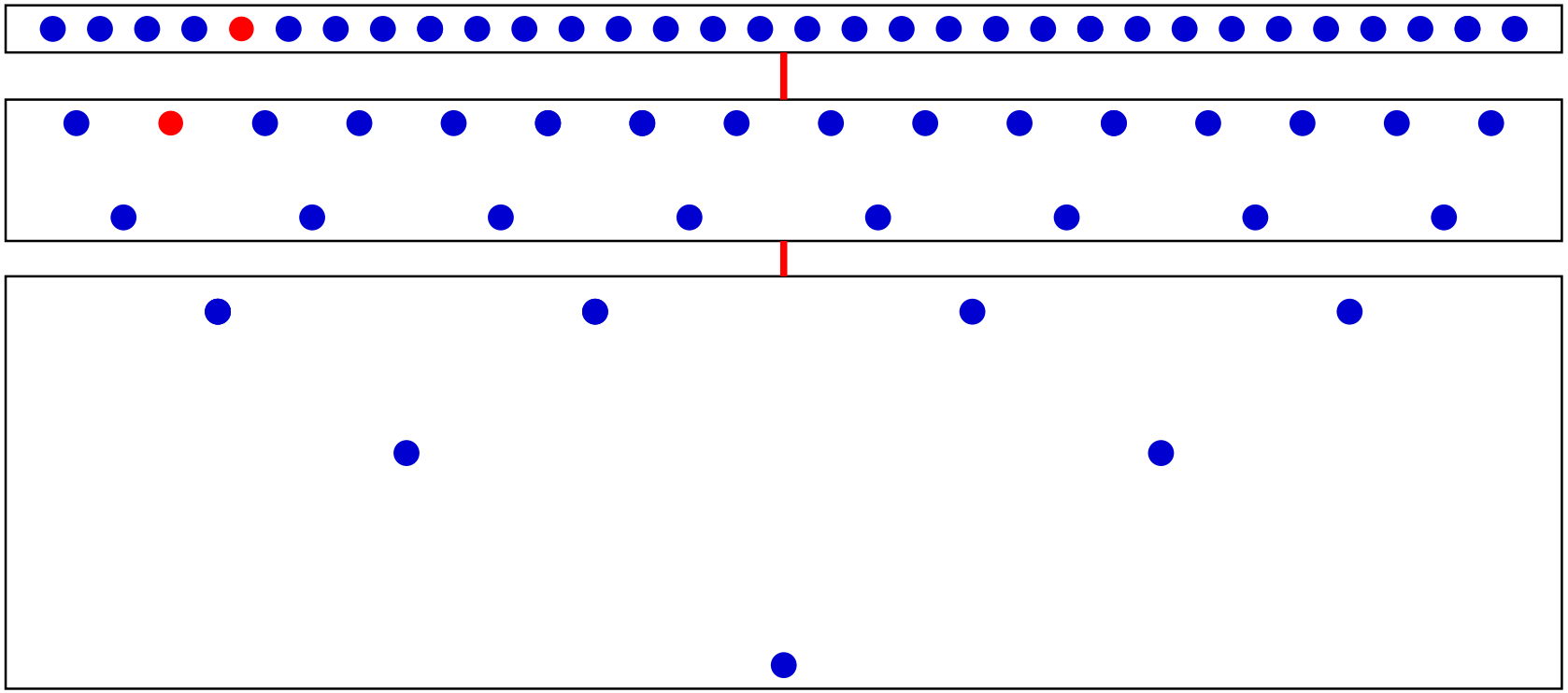

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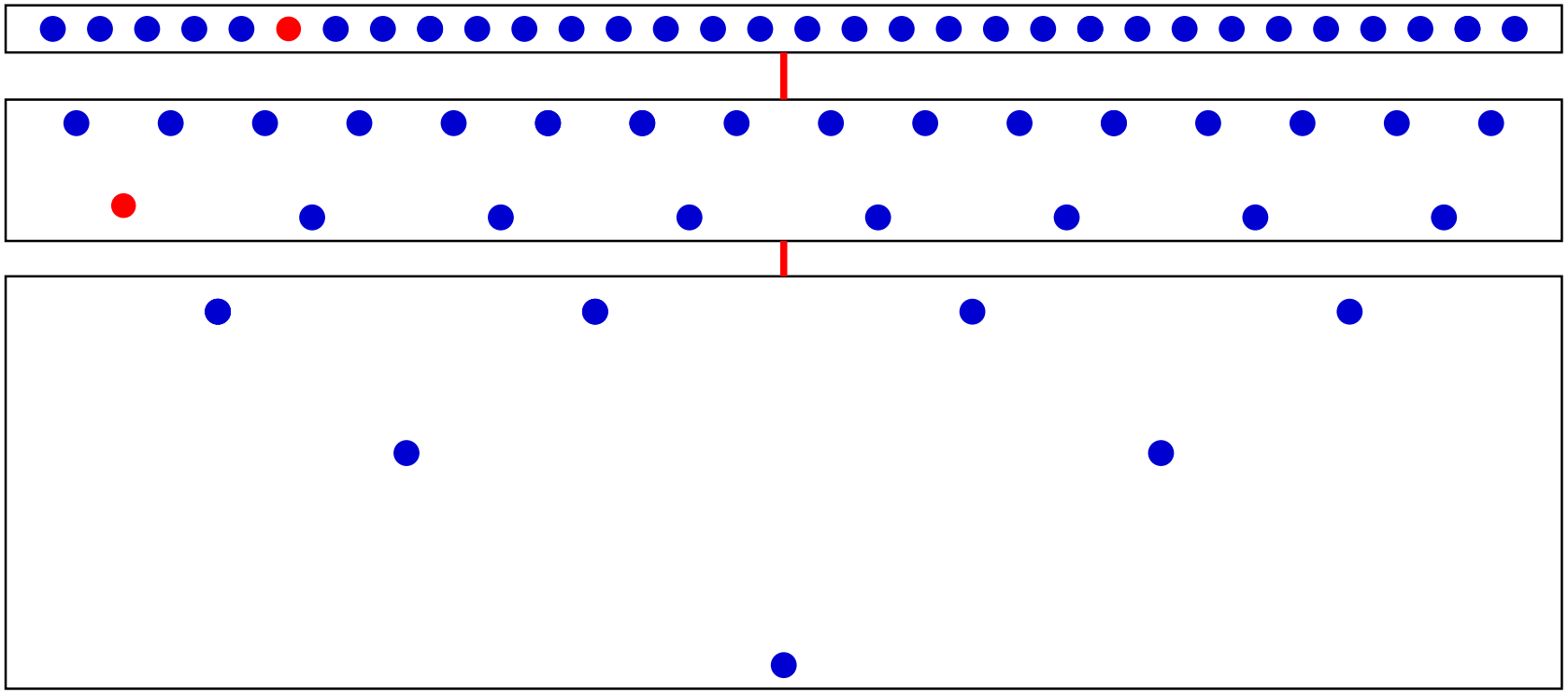

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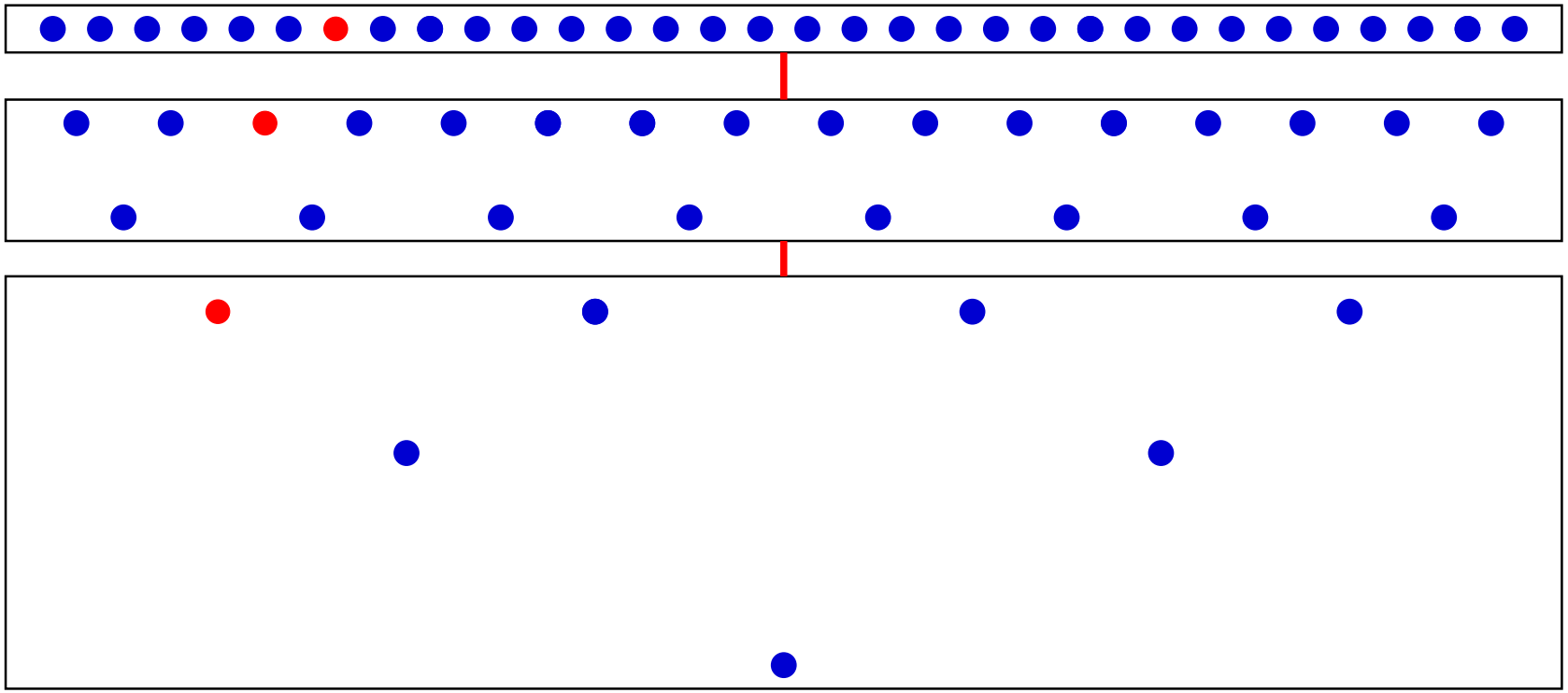

Higher Level Performance Optimisation

Structured Parallelism matters because it allows us to manipulate parallel algorithms at a coarse structural level.

Who cares?

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Skeletal programming remains a fringe activity

A Pragmatic Manifesto

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MPI's collectives are simple skeletons, so build on this.

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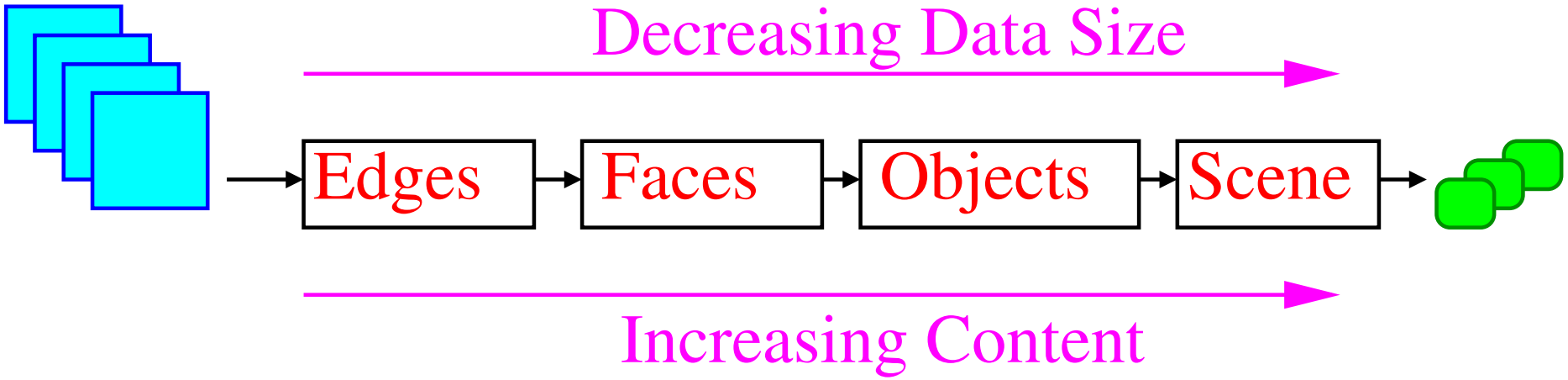
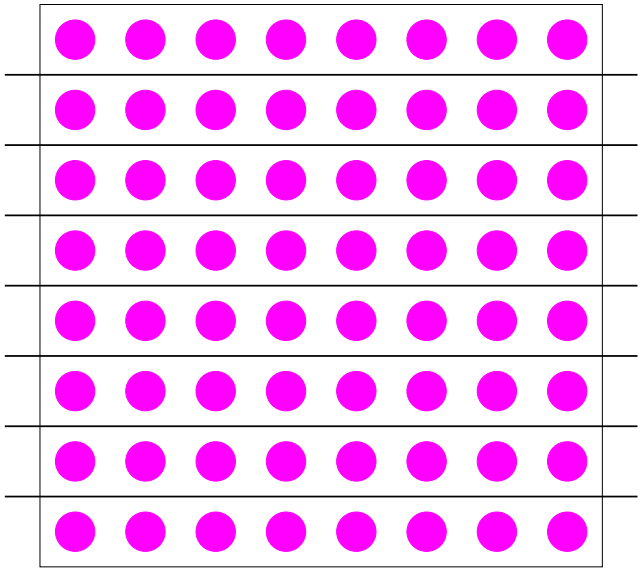
A Vanilla Pipeline - Image Processing



An Exotic Pipeline - Gaussian Elimination



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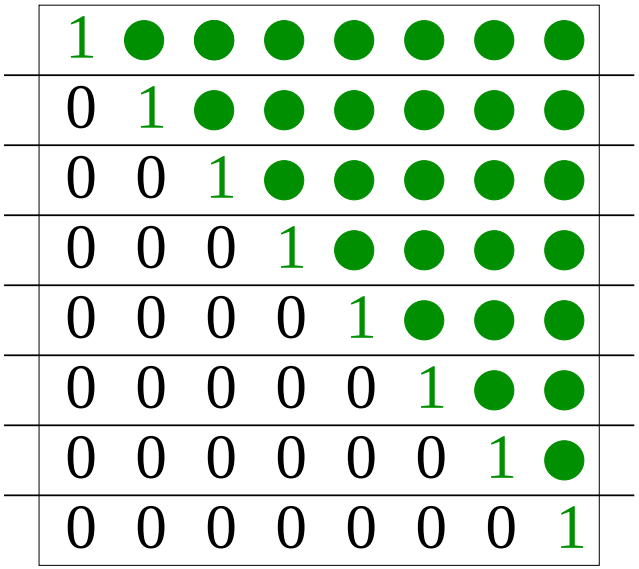

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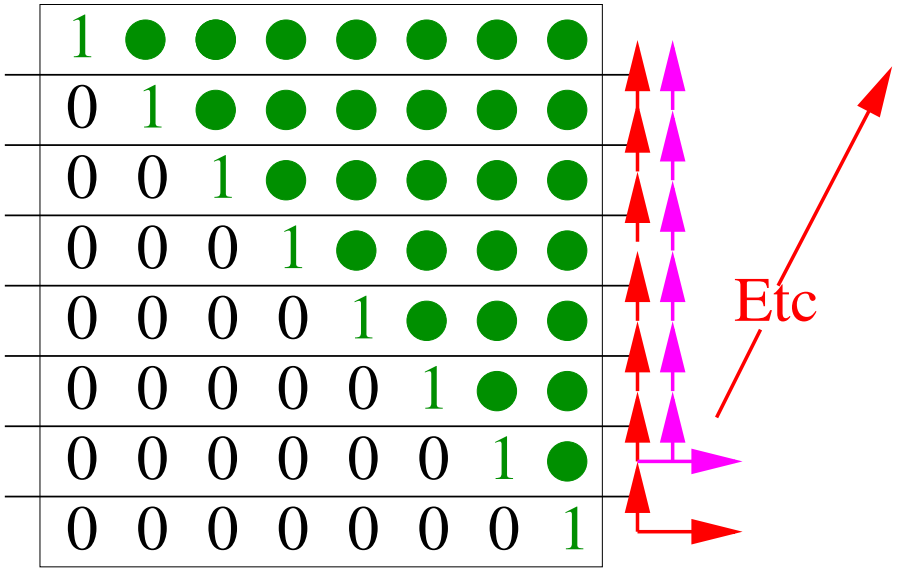
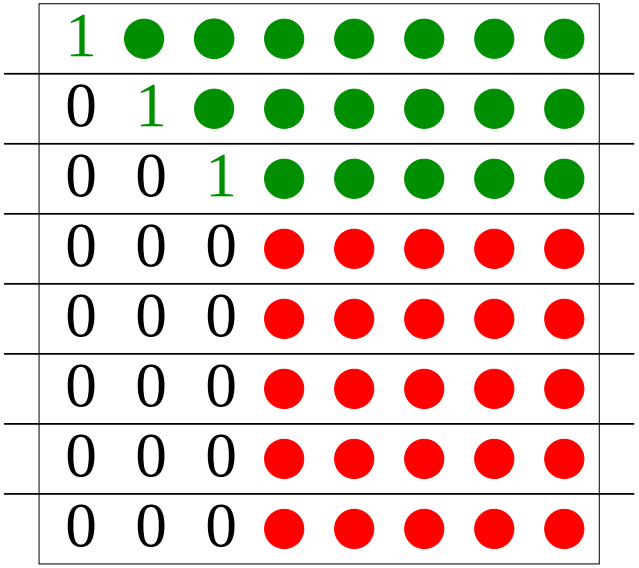


Elimination Phase

```
for (each row in sequence) {

     normalise this ‘‘pivot’’ row;

     broadcast result to subsequent rows;

     for (each subsequent row in parallel) {

         eliminate one column using broadcast row
     }
}
```

Elimination Phase



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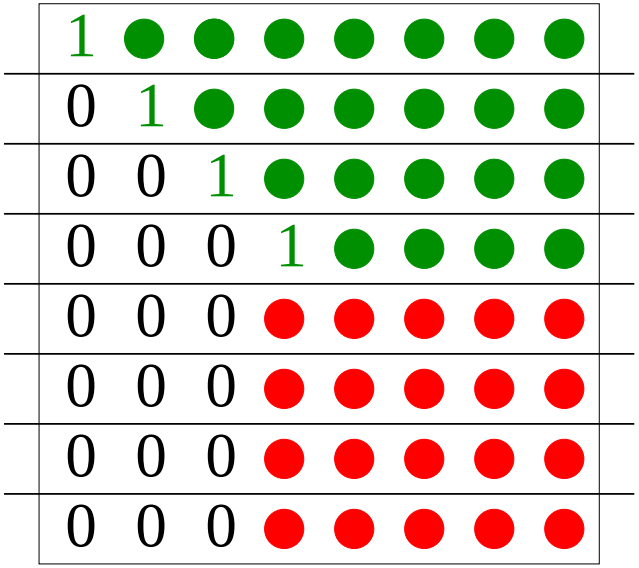

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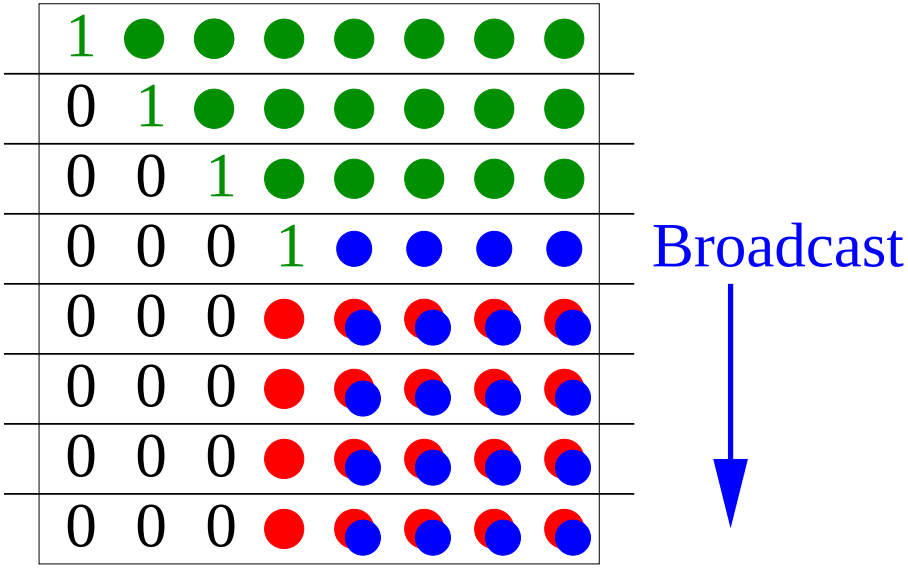

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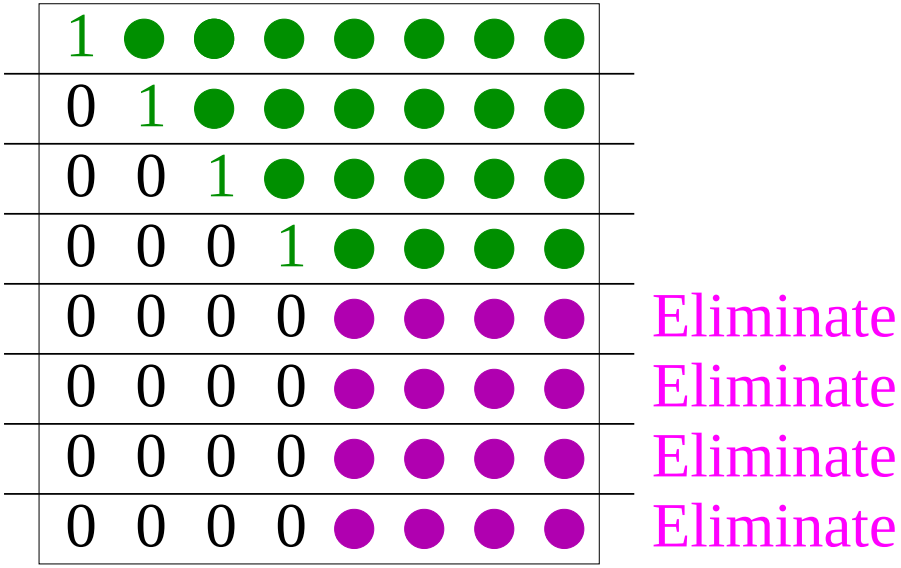

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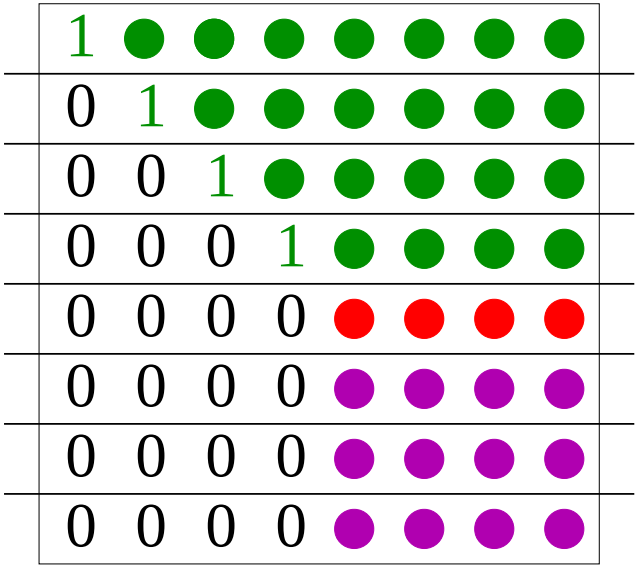

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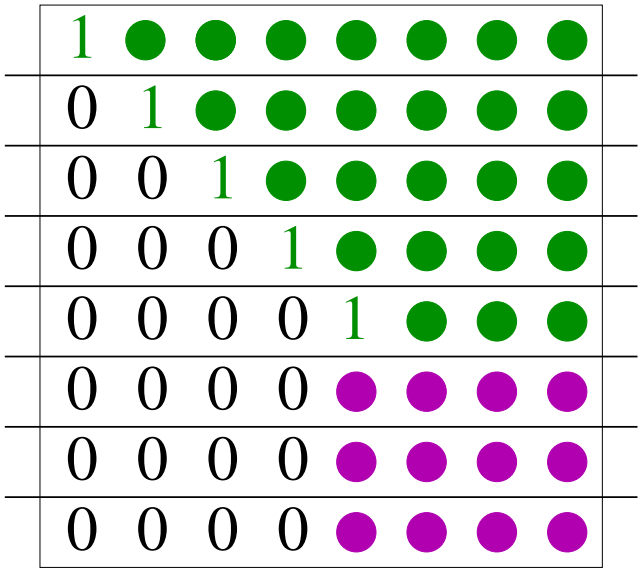

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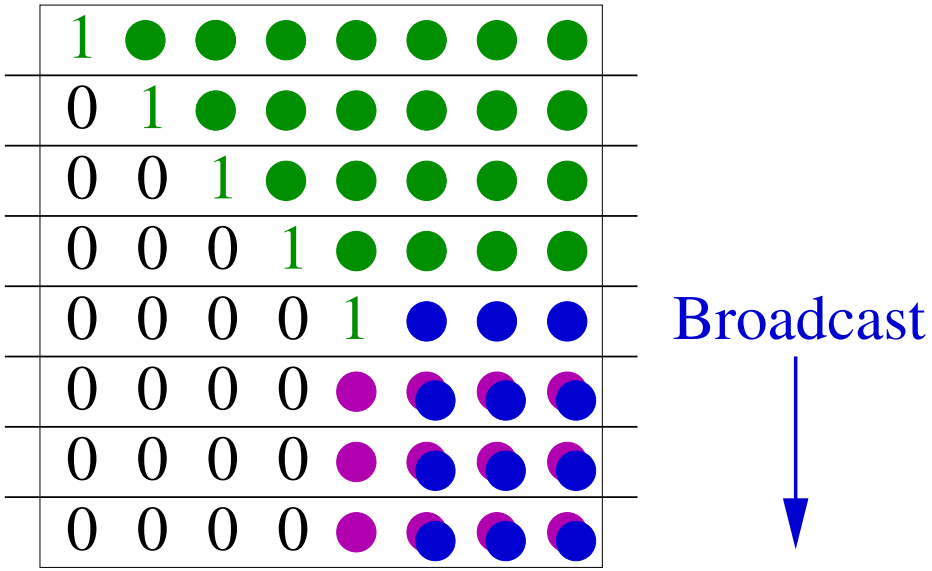

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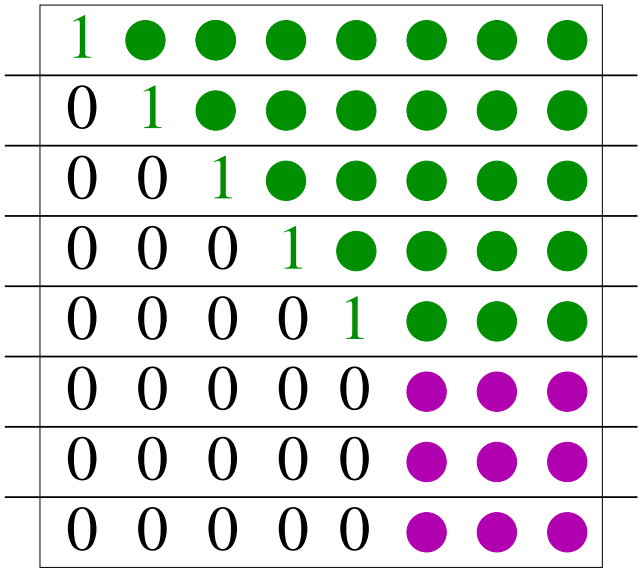

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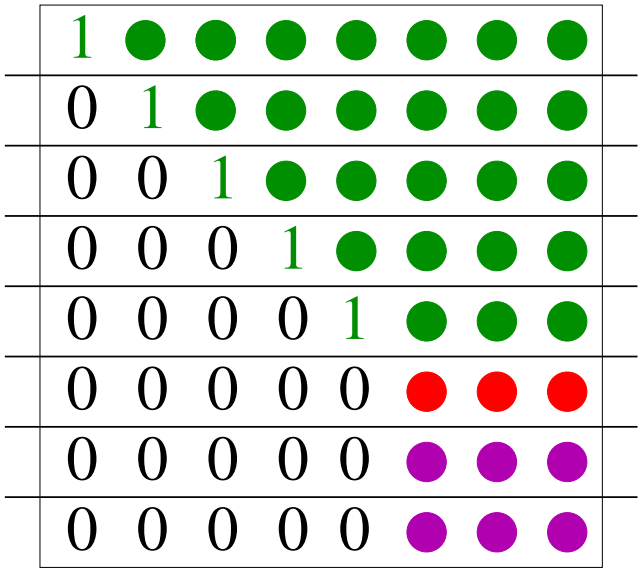

Pipelined Version

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Textbook improvement interleaves broadcast and elimination phases.

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Processors

- participate in broadcast
- begin elimination immediately (before broadcast completes elsewhere)
- iterations become pipelined

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Each iteration would be slower independently, but pipelining across iterations produces an overall gain.

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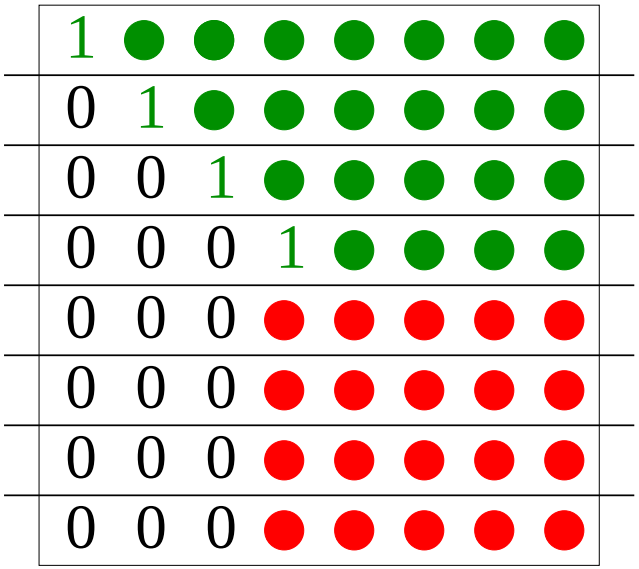

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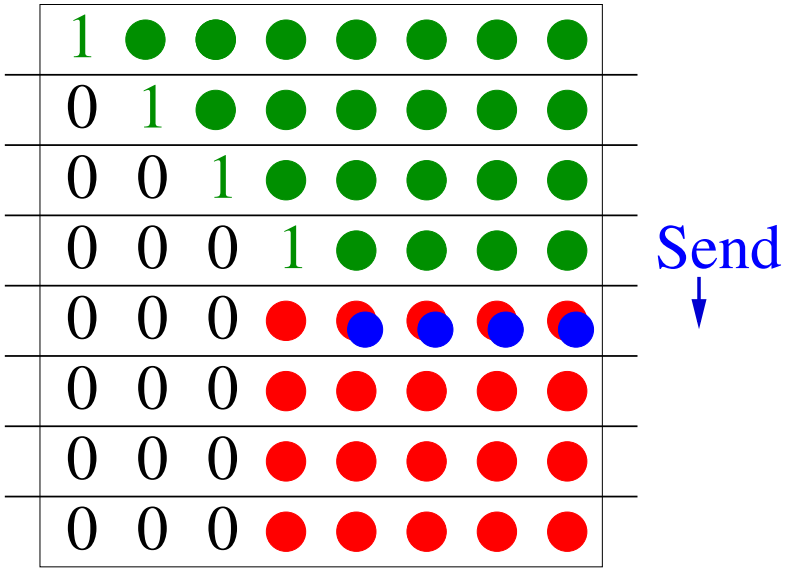

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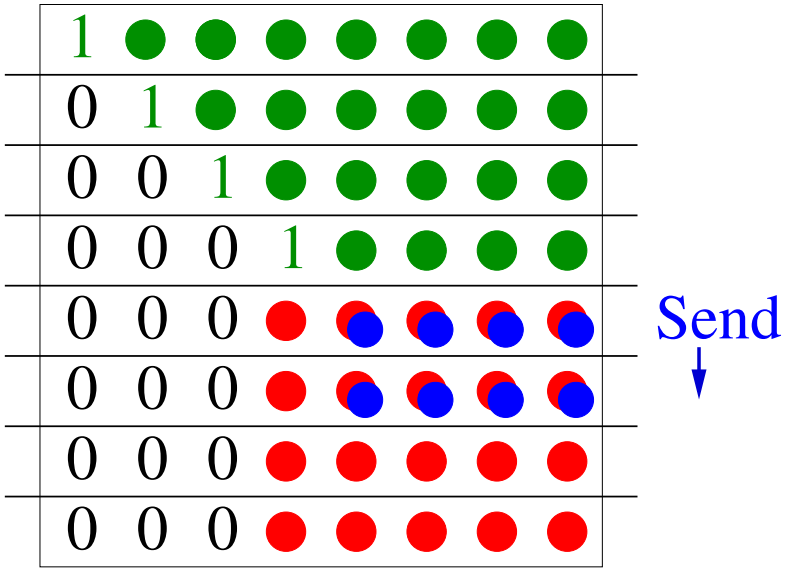

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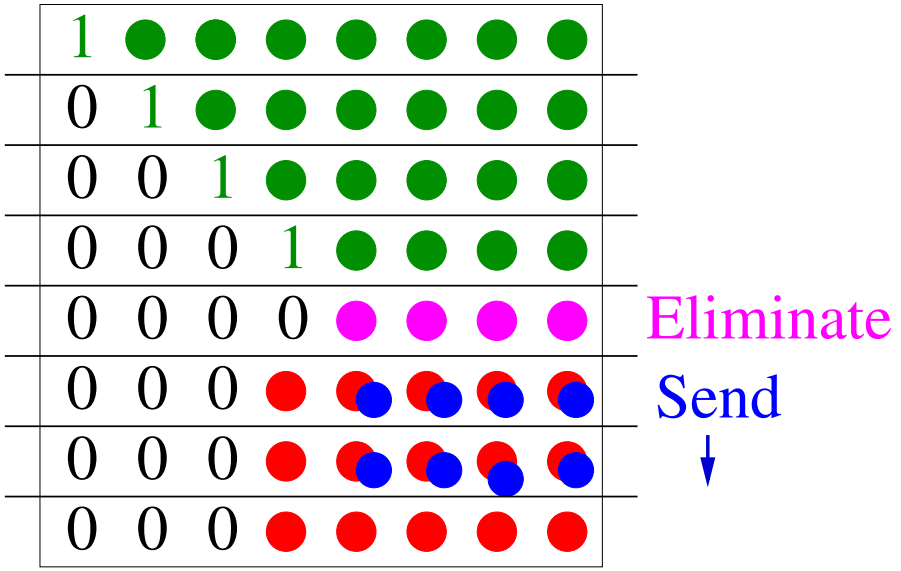

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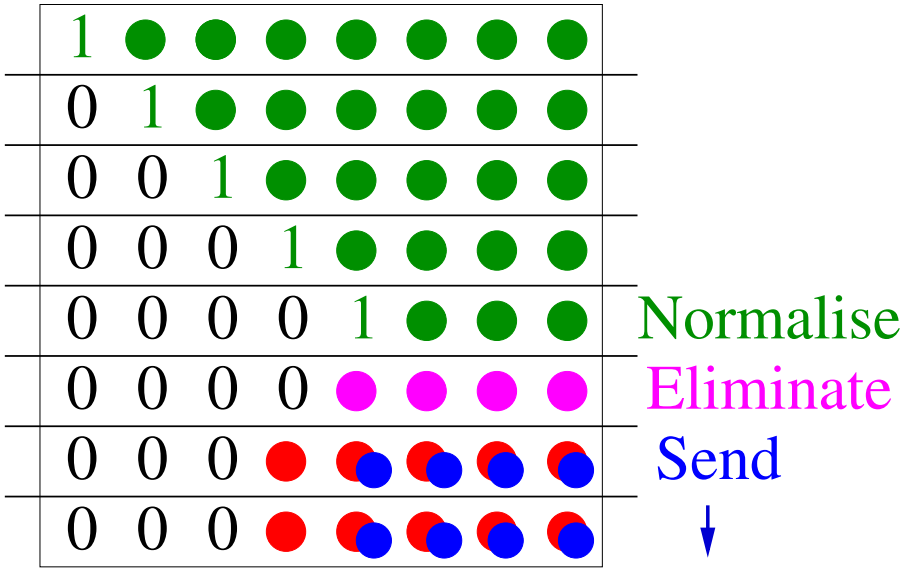

Observations

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There are no external buffers of input or output (both are in the stage state).

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Sequence of interactions is state dependent (activity is different the "final time").

More Pipelining

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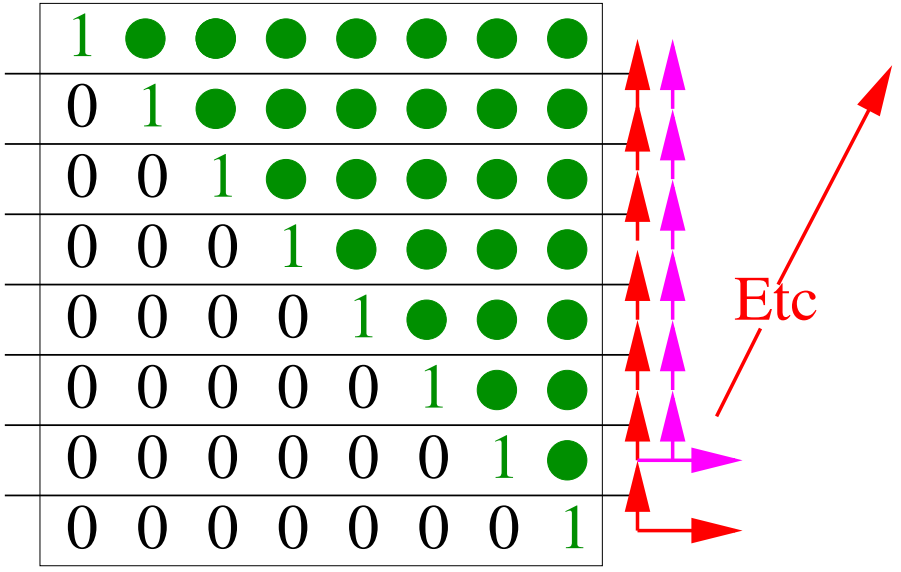

Algorithm Summary

```
Scatter_data();                                          // standard MPI

Pipeline (top-to-bottom, elimination, ....);             // skeleton call

Pipeline (bottom-to-top, back_substitution, ....); // skeleton call

Gather_results();                                        // standard MPI
```

eSkel

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The edinburgh Skeleton library

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An experimental attempt to address these issues.

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An extension of MPI's collective operation suite.

MPI Key Concepts

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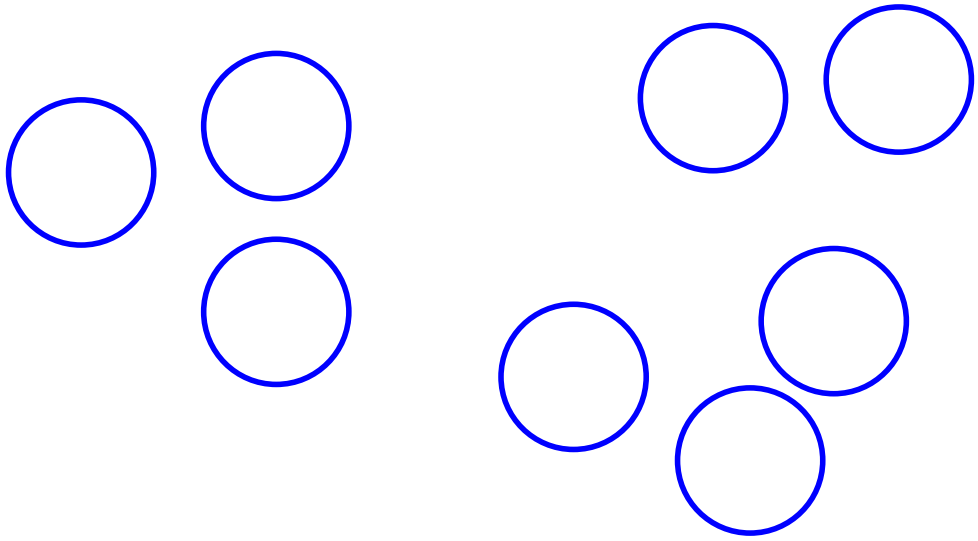
Every communication specifies its communicator.

Allows programmer to reflect logical groupings in an algorithm and to insulate communications within these from "outside" interference.

MPI Communicators



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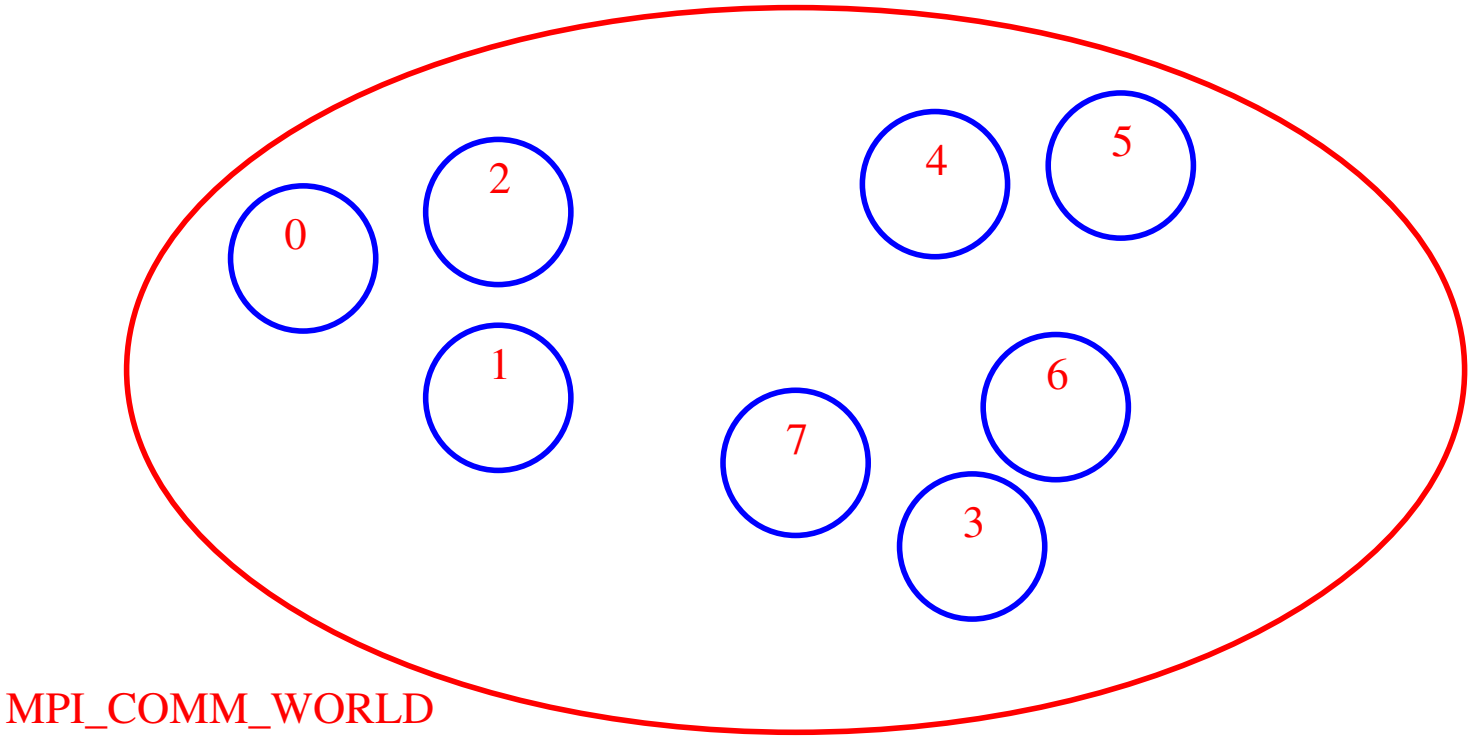

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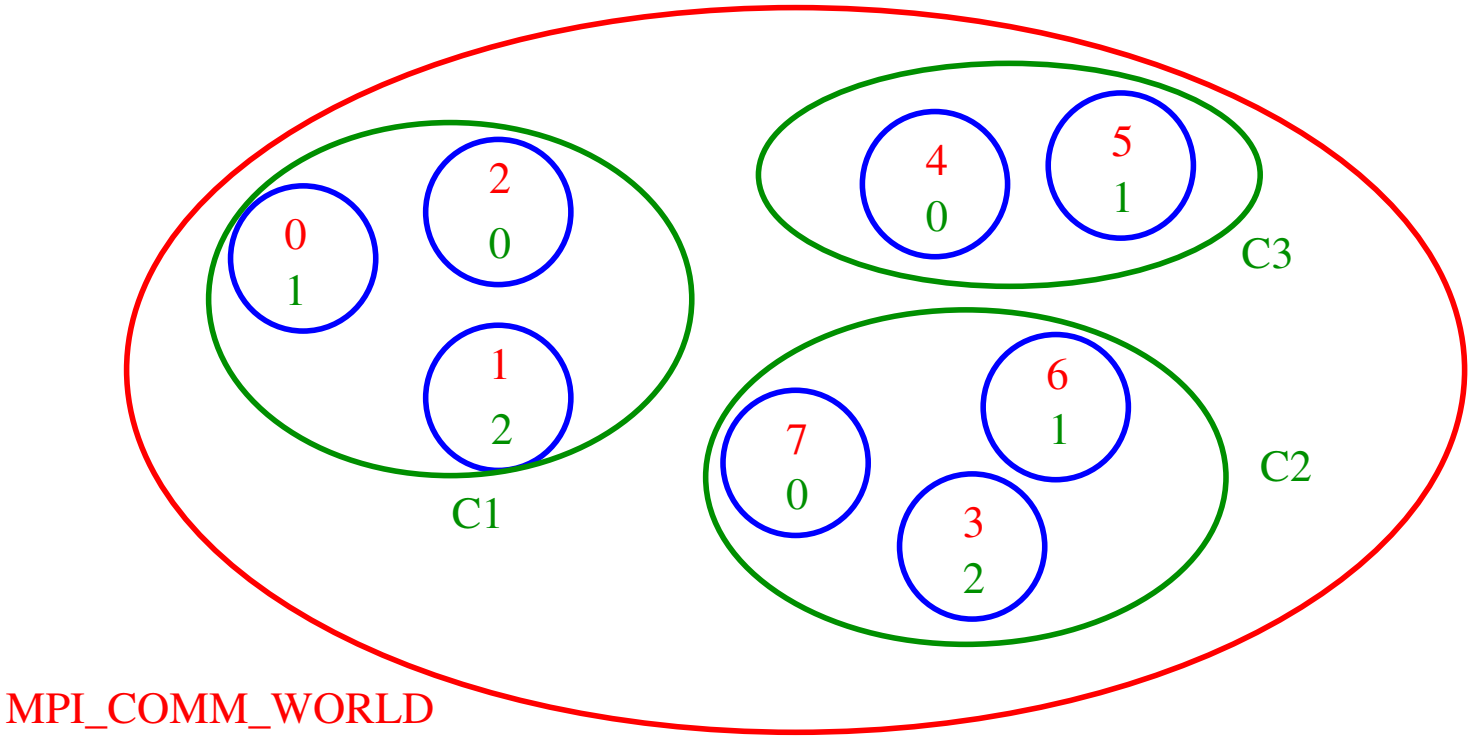

MPI: Collective Operations

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int MPI_Reduce (void * sndbuf, void * rcvbuf, int count, MPI_Datatype dt,
                MPI_Op op, int root, MPI_Comm comm)
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- input data buffer (each process contributes)
- output buffer (note restriction on type)
- operation to be used
- group and special roles within it (in this case, root receives the result)

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We design eSkel from this basis to provide

- minimal conceptual disruption (principle 1)
- ad-hoc parallelism (principle 2)

eSkel Skeletons

The current draft of eSkel defines five skeletons

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Pipeline

Farm

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Farm

Deal

HaloSwap

Butterfly

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Similar to a farm, but distributes task in cyclic order to workers (no farmer).

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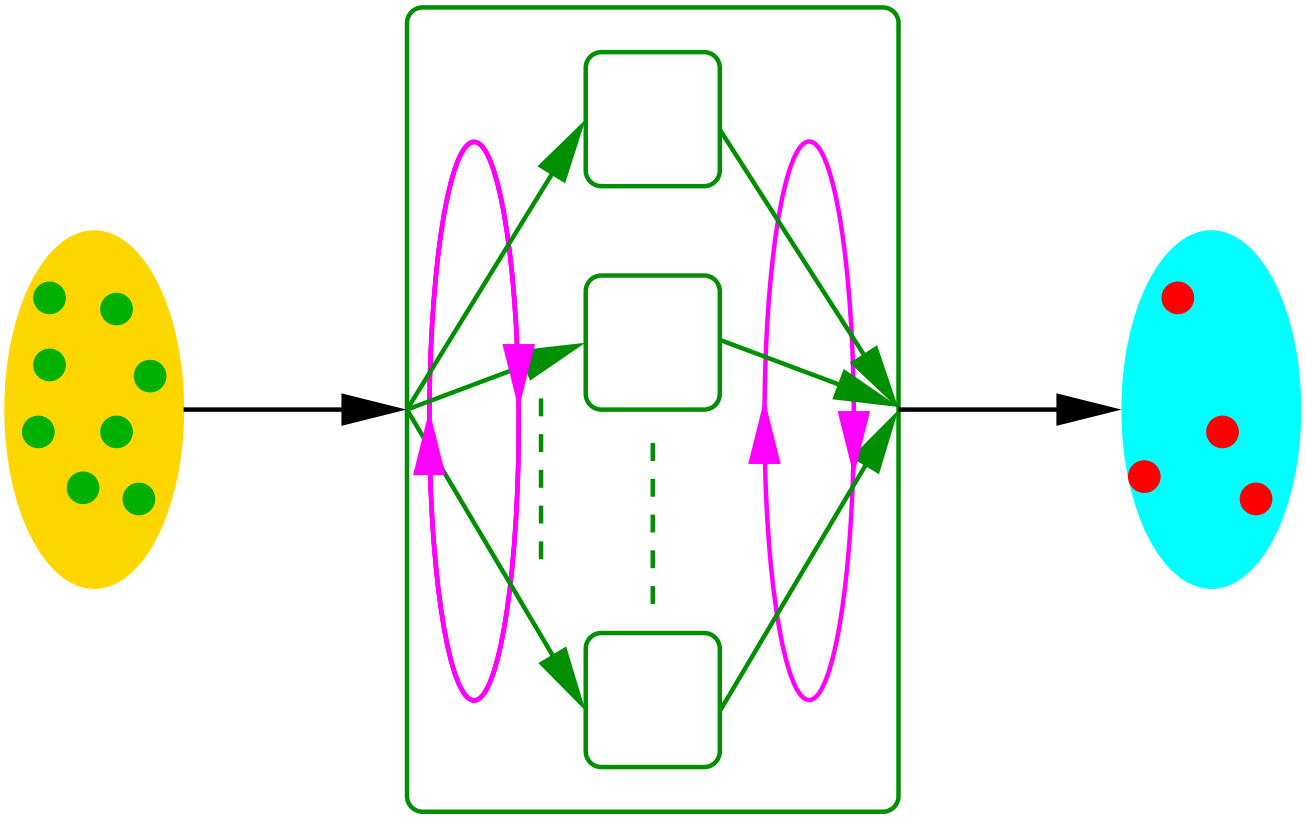
Useful nested in pipelines, to internally replicate a stage.

Deal



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Optional wraparound.

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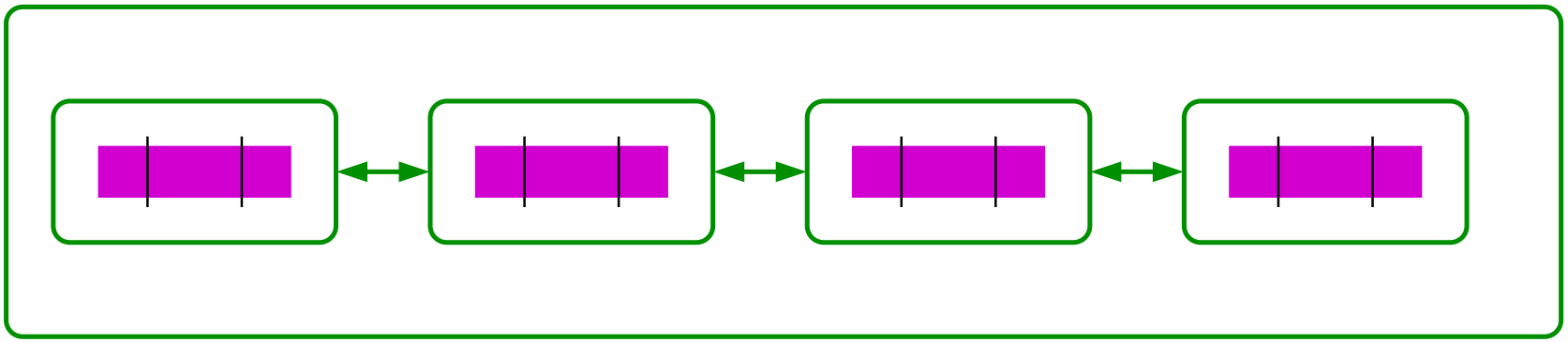

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Captures a class of divide-and-conquer algorithms (those based on traversing hypercube dimensions).

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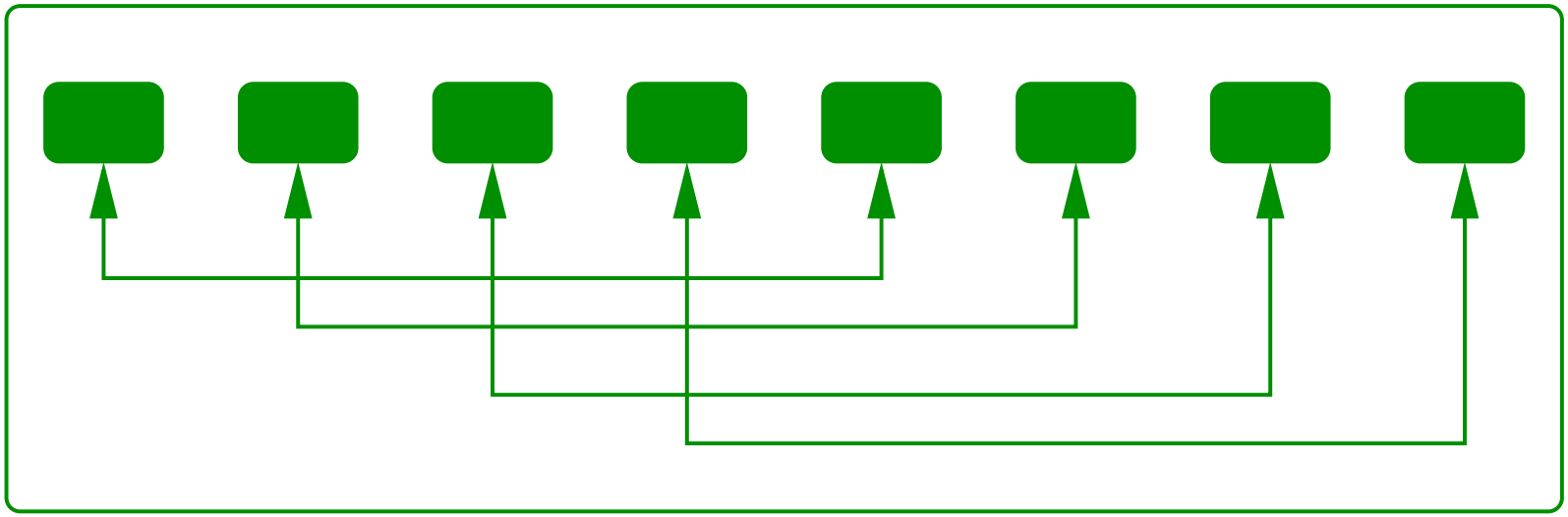
Constrained to work with 2^d processes.

Butterfly



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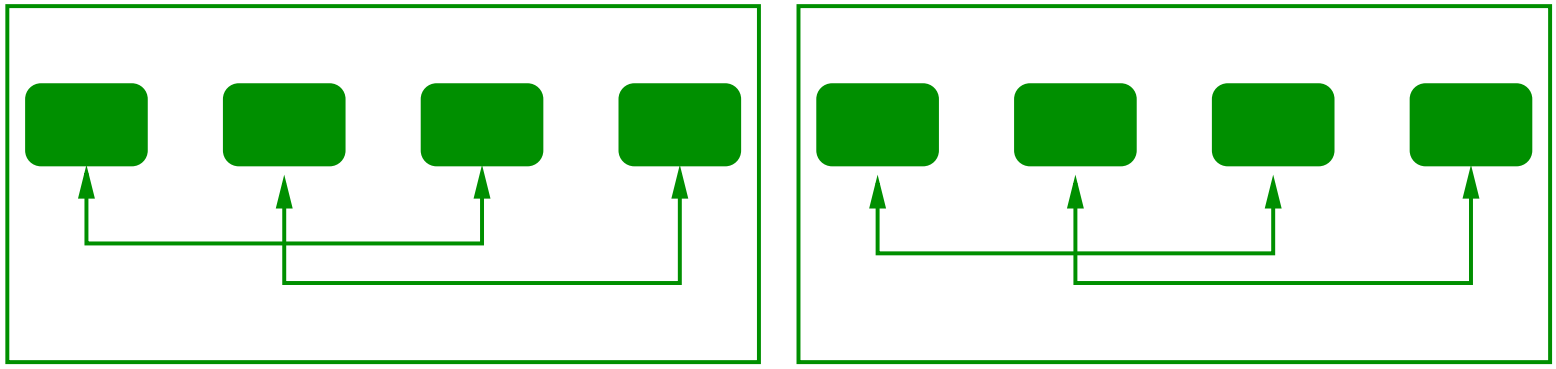

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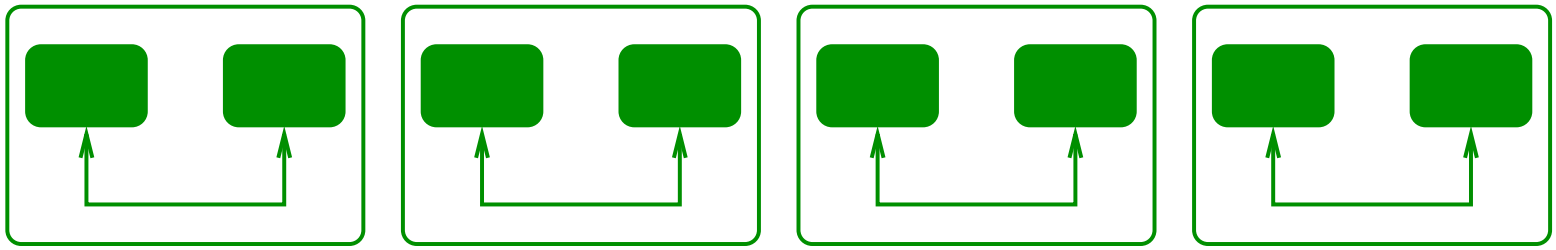

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Because of the MPI basis and for flexibility.

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Pipeline stage activities

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Why do we need fifteen parameters?

Stage interfaces and modes

Summary

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To enter the mainstream we have to be pragmatic.

Future Work

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