Replicators
(components and test-rigs)

Peter Welch (p.h.welch@kent.ac.uk)

Computing Laboratory, University of Kent at Canterbury

Co631 (Concurrency)

Replicators *(components and test-rigs)*

Replicated **PAR** and **SEQ** ...

The **SORT PUMP** …

Component testing …

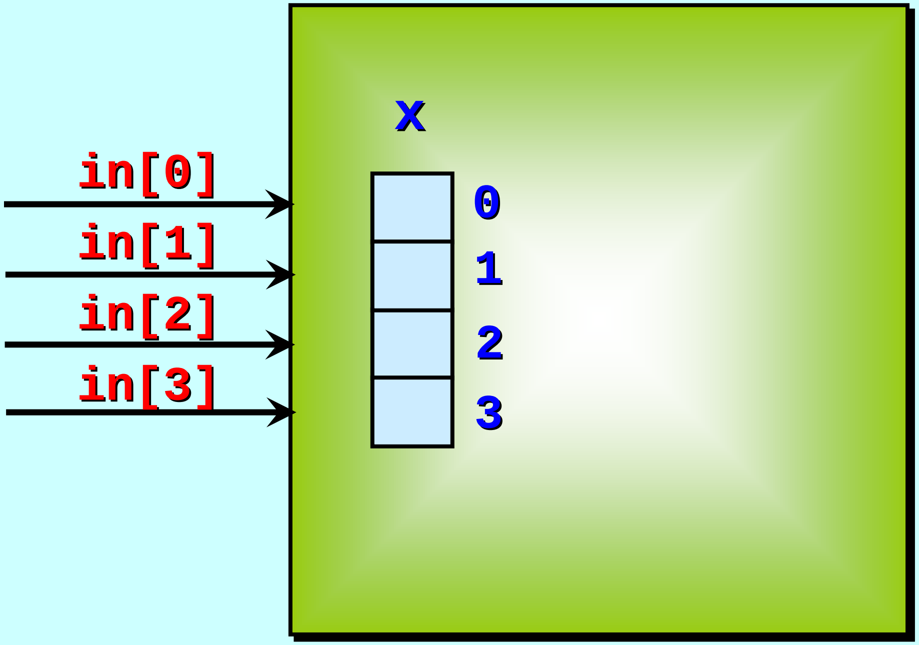
Stateless components …

The **SORT GRID** …

Replicated **IF** …

Replicator **STEP** sizes …

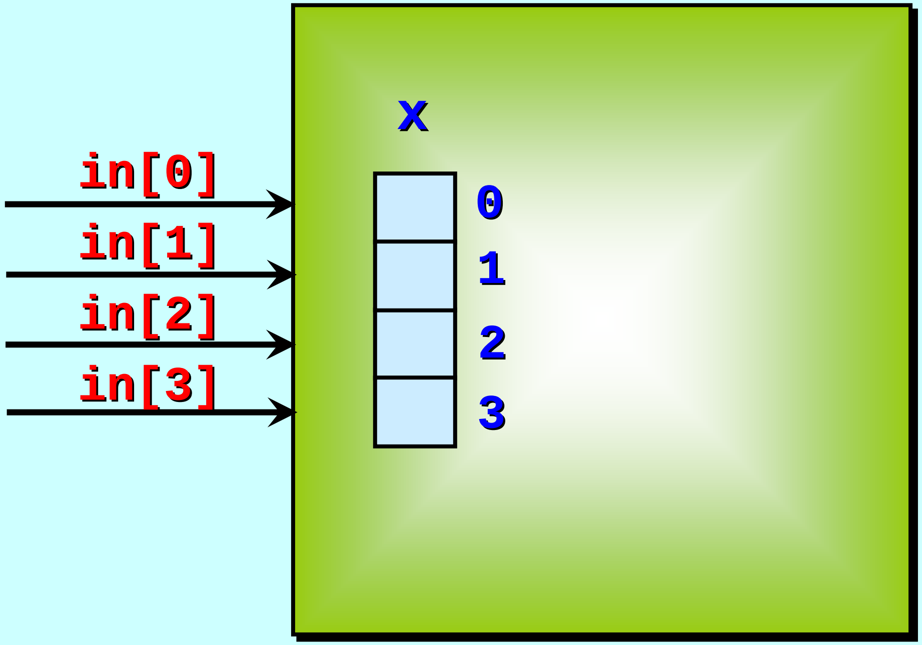
Consider a process with an array of input channels:



And an internal data array, **x**, of the same type and size as the input channel array.

The process needs to input one message from each input channel into the corresponding element of its data array.

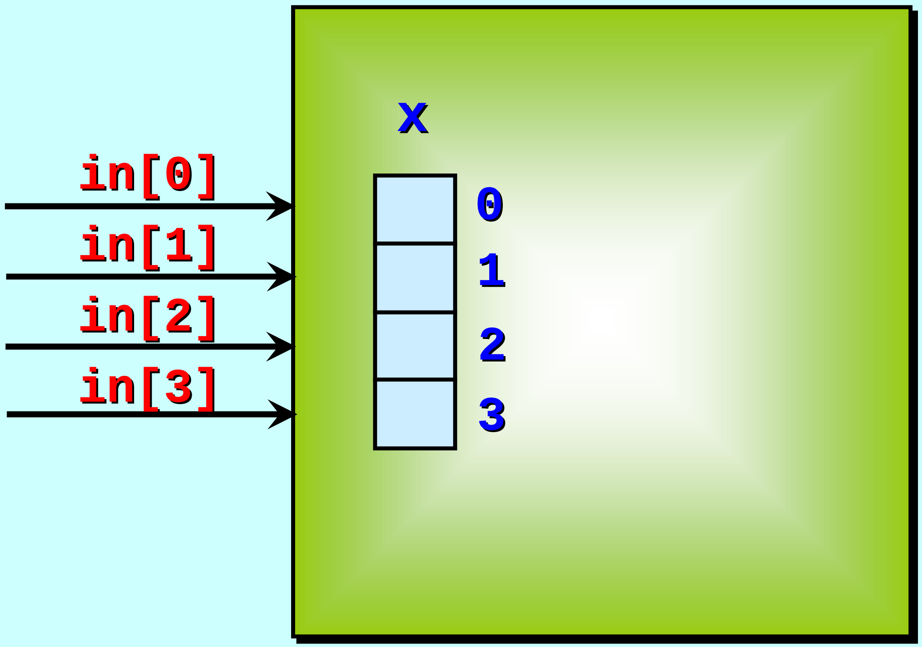
These inputs are to be done *in parallel*:




```
PAR
  in[0] ? x[0]
  in[1] ? x[1]
  in[2] ? x[2]
  in[3] ? x[3]
```

Golden Rule:
when communications can be done in parallel, *do them in parallel*.

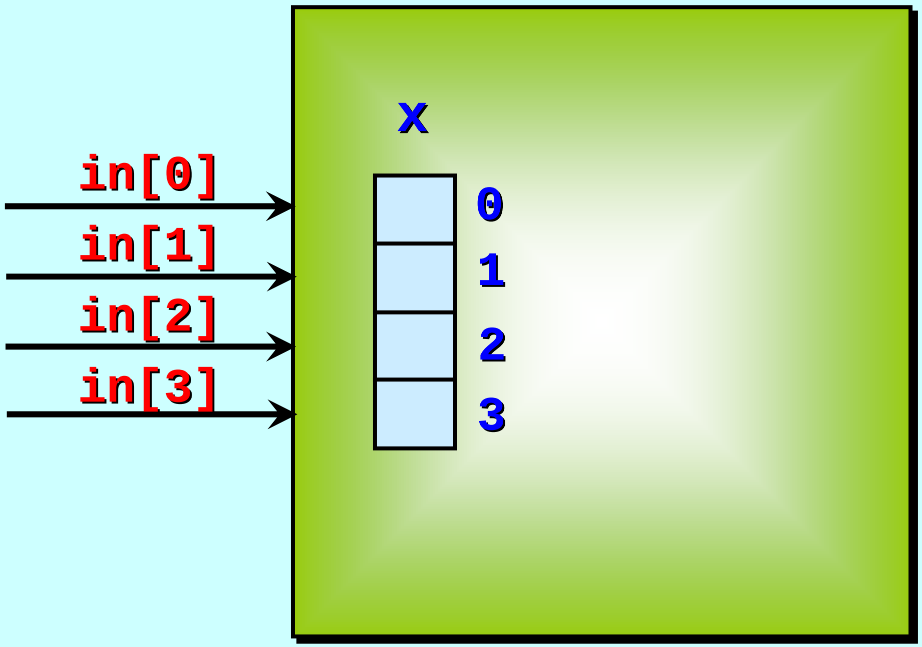
These inputs are to be done *in parallel*:




```
PAR
  in[0] ? x[0]
  in[1] ? x[1]
  in[2] ? x[2]
  in[3] ? x[3]
```

But what if there were 40 channels in the array? Or 400 … or 4000 … ?!!

These inputs are to be done *in parallel*:



INT declaration

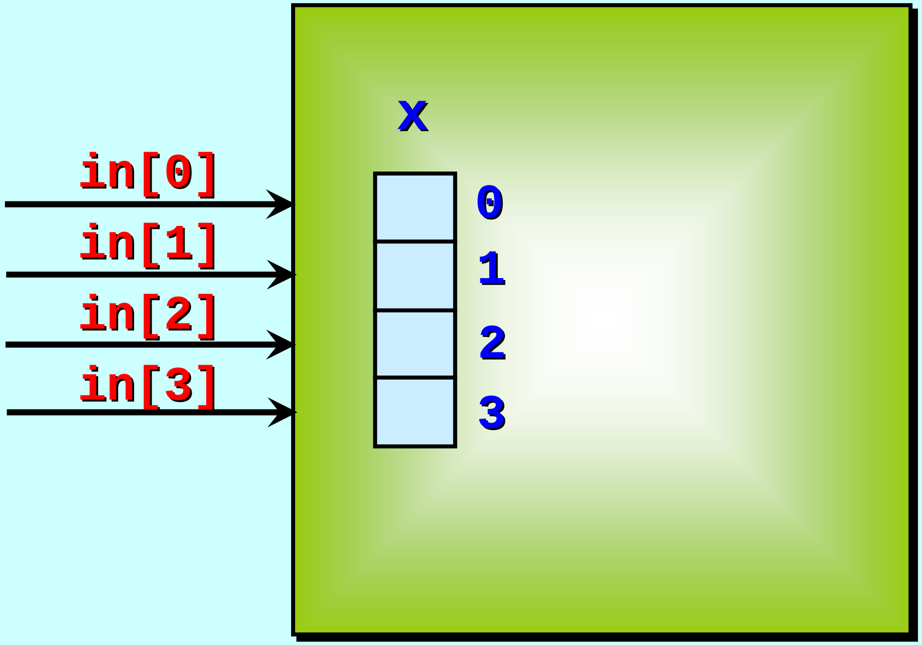
first value

number of replications

```
PAR i = 0 FOR 4
  in[i] ? x[i]
```

This process gets replicated

These inputs are to be done *in parallel*:

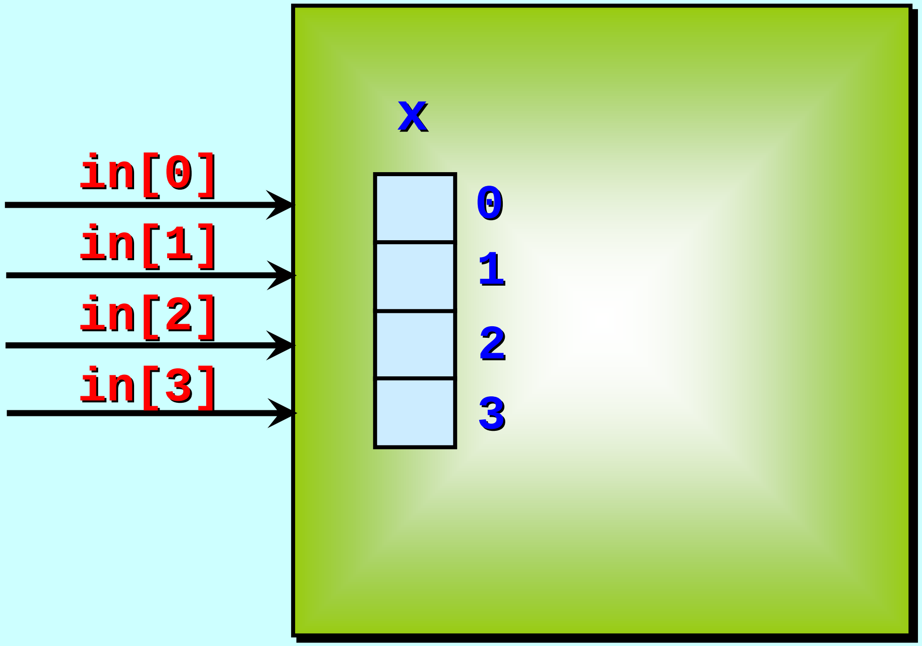



```
PAR i = 0 FOR 4
  in[i] ? x[i]
```

≡

```
PAR
  in[0] ? x[0]
  in[1] ? x[1]
  in[2] ? x[2]
  in[3] ? x[3]
```

Just in case they really had to be done *in sequence*:



INT declaration

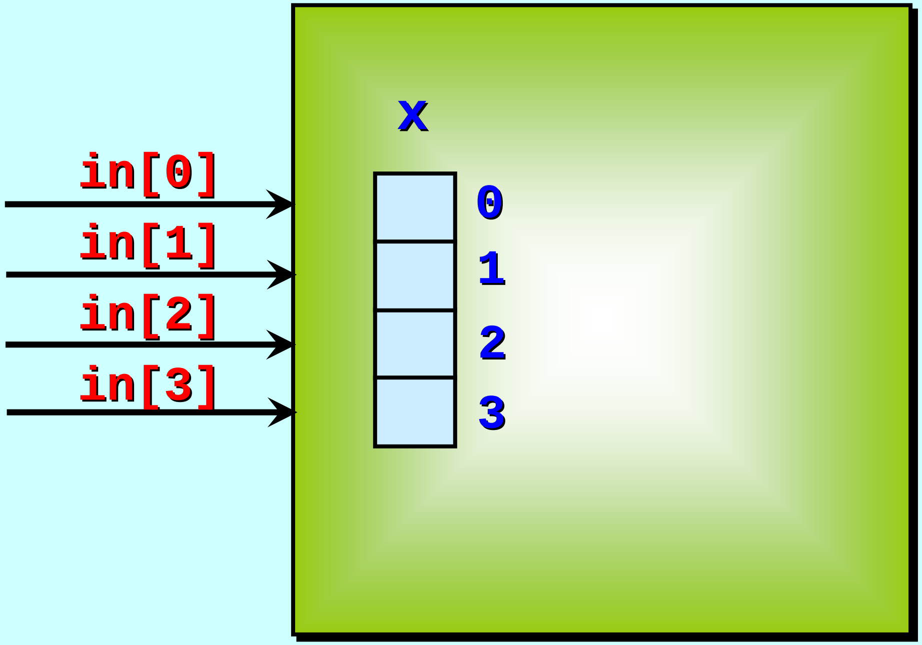
first value

number of replications

```
SEQ i = 0 FOR 4
  in[i] ? x[i]
```

This process gets replicated.

Just in case they really had to be done *in sequence*:




```
SEQ i = 0 FOR 4
  in[i] ? x[i]
```

≡

```
SEQ
  in[0] ? x[0]
  in[1] ? x[1]
  in[2] ? x[2]
  in[3] ? x[3]
```

The replicated SEQ is like a very clean for-loop.

INT declaration

first value

number of replications

```
SEQ i = start FOR count
  <process i>
```

In Java or C:

```
for (int i = start; i < (start + count); i++) {
  <code i>
}
```

Must not change the value of i, start or count

The replicated PAR has no correspondence in Java or C.

INT declaration

first value

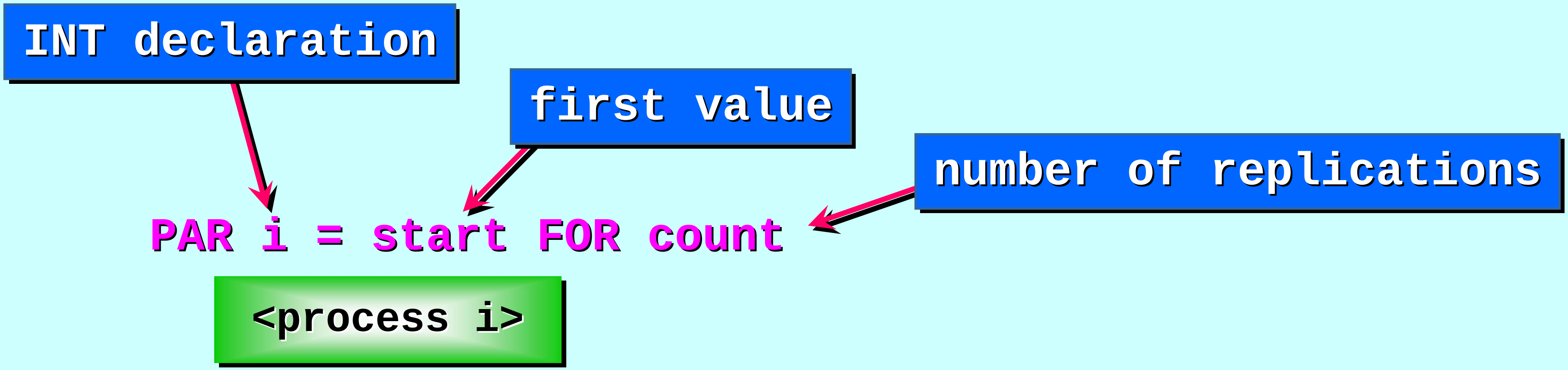
number of replications

```
PAR i = start FOR count
  <process i>
```

In Java or C:

… silence

Applying the replicated PAR.



The first example showed parallel replication of a *primitive* process (an input process).

But, earlier, we've seen parallel composition of long-lived *structured* processes (like continuously active 'chips').

The next example shows parallel replication of such a process to build a *parallel sorting engine*.

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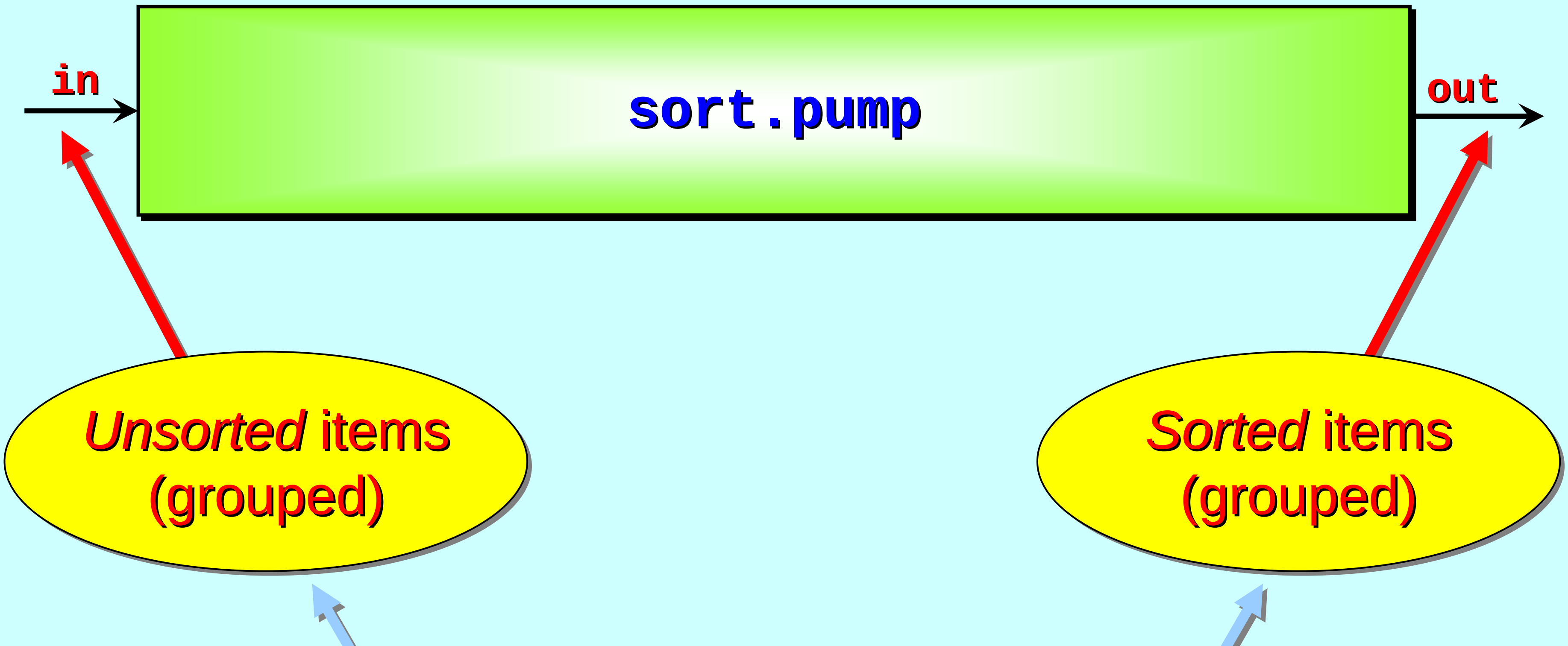
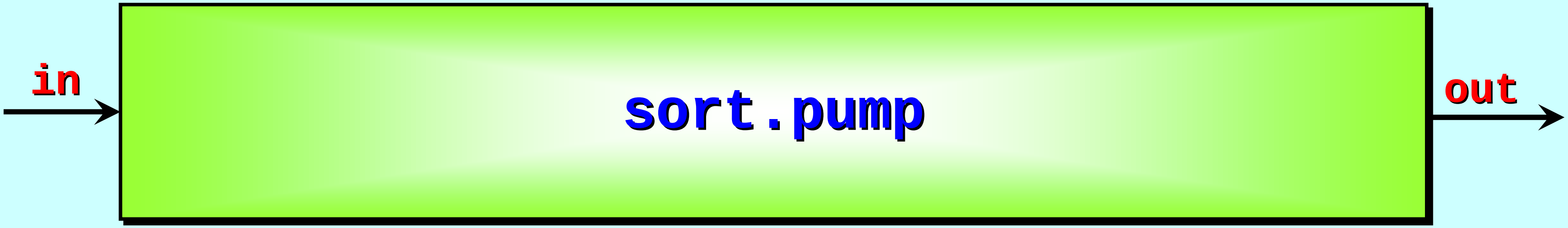
Replicator **STEP** sizes …



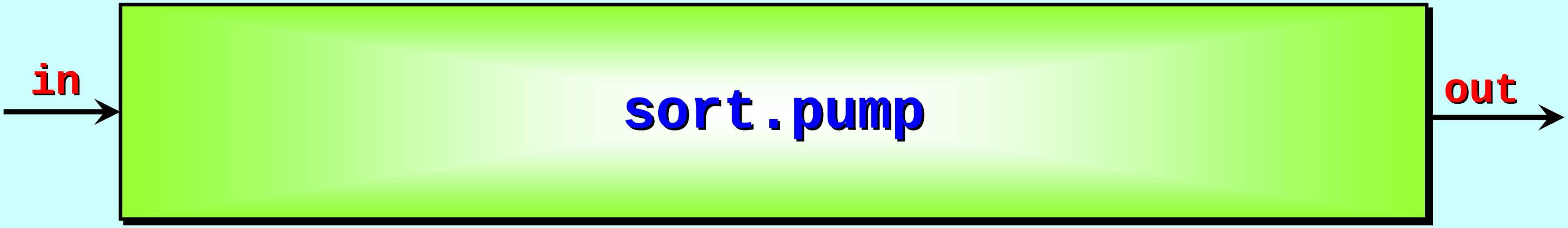
8, 99, 42, 4, 6, 21, 55, 7, 255,
65, 92, 32, 54, 255,
111, 10, 5, 60, 48, 69, 7, 255
…

4, 6, 7, 8, 21, 42, 55, 99, 255,
32, 54, 65, 92, 255,
5, 7, 10, 48, 60, 69, 111, 255
…



8, 99, 42, 4, 6, 21, 55, 7, 255,
65, 92, 32, 54, 255,
111, 10, 5, 60, 48, 69, 7, 255
...

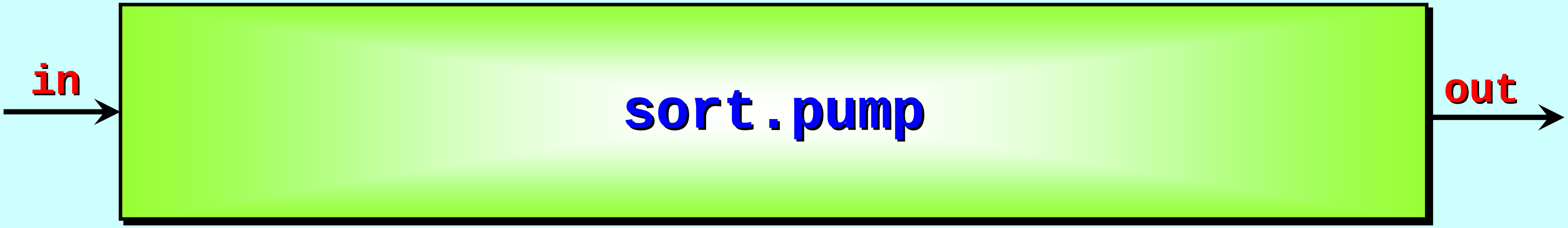
4, 6, 7, 8, 21, 42, 55, 99, 255,
32, 54, 65, 92, 255,
5, 7, 10, 48, 60, 69, 111, 255
...



8, 99, 42, 4, 6, 21, 55, 7, 255,
65, 92, 32, 54, 255,
111, 10, 5, 60, 48, 69, 7, 255
…

4, 6, 7, 8, 21, 42, 55, 99, 255,
32, 54, 65, 92, 255,
5, 7, 10, 48, 60, 69, 111, 255
…

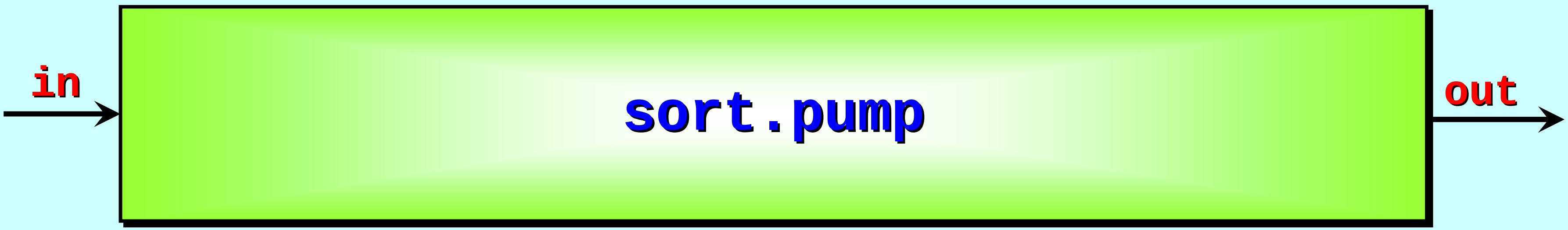
Note: 255 is used here to mark the end of each group.



8, 99, 42, 4, 6, 21, 55, 7, 255,
65, 92, 32, 54, 255,
111, 10, 5, 60, 48, 69, 7, 255
…

4, 6, 7, 8, 21, 42, 55, 99, 255,
32, 54, 65, 92, 255,
5, 7, 10, 48, 60, 69, 111, 255
…

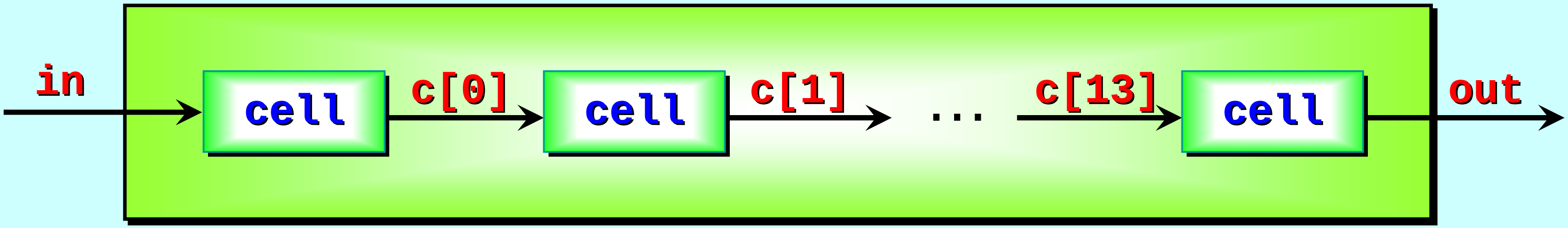
For the efficient application of this device, we need a long-running source of groups of items that need sorting. We also need to specify an upper limit on the size of groups.



8, 99, 42, 4, 6, 21, 55, 7, 255,
65, 92, 32, 54, 255,
111, 10, 5, 60, 48, 69, 7, 255
...

4, 6, 7, 8, 21, 42, 55, 99, 255,
32, 54, 65, 92, 255,
5, 7, 10, 48, 60, 69, 111, 255
...

An example is a simple image smoothing filter: each pixel is replaced by the *median* value of its (9) neighbours. Finding median values implies sorting. Each n-by-m image generates (n*m) groups of 9 numbers for sorting.

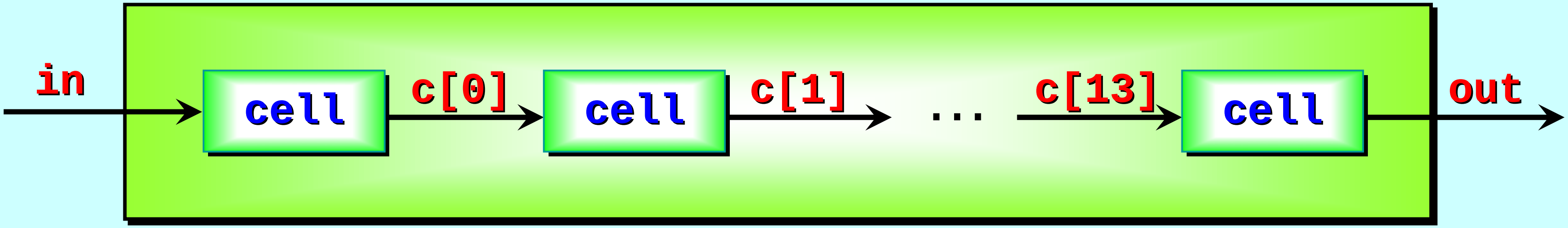


The **sort.pump** is implemented as a *pipeline* of simpler **cell** proccesses. *(We'll see what they do presently.)*

To sort groups up to a maximum size of **max**, we need at least (**max – 1**) **cell**s.

So, if **max** is **16**, we need **15 cell**s … which means we need **14** internal channels … which we have indexed above from **0** through **13**.

```
VAL INT max IS 16:
```



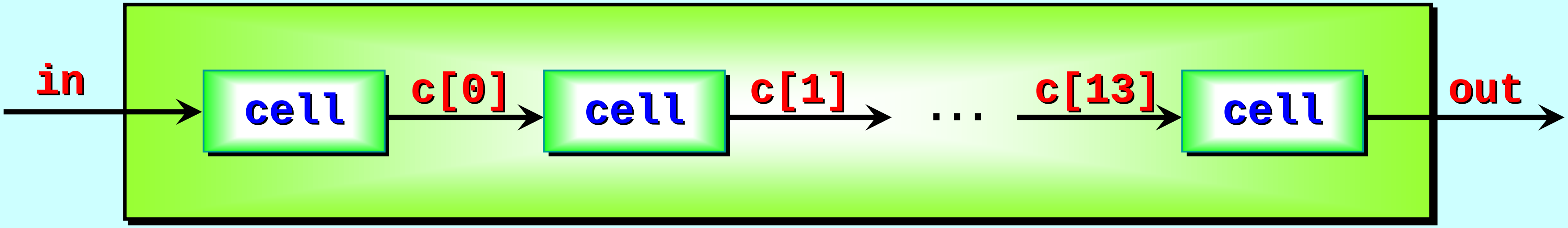

```
PROC sort.pump (CHAN BYTE in?, out!)
  [max-2]CHAN BYTE c:
  PAR
    cell (in?, c[0]!)
    PAR p = 1 FOR max-3
      cell (c[p-1]?, c[p]!)
    cell (c[max-3]?, out!)
:
```

1 cell

(max-3) cells

1 cell

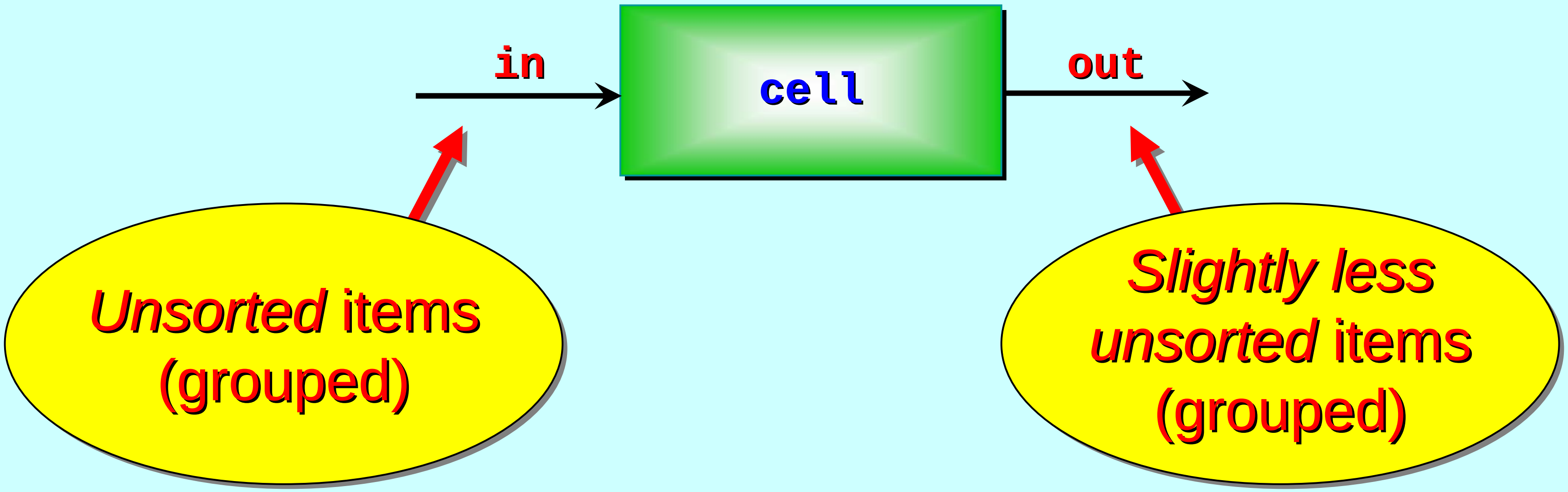
```
VAL INT max IS 16:
```




```
PROC sort.pump (CHAN BYTE in?, out!)
  [max-2]CHAN BYTE c:
  PAR
    cell (in?, c[0]!)
    PAR p = 1 FOR max-3
      cell (c[p-1]?, c[p]!)
    cell (c[max-3]?, out!)
:
```

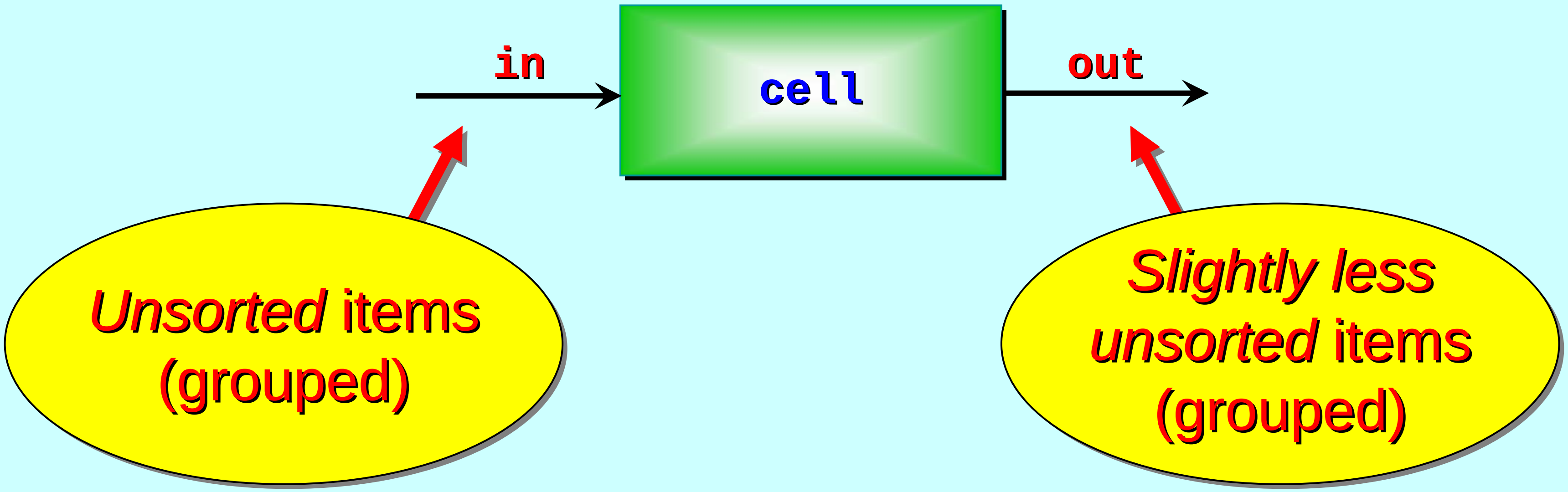
So, we have (max-1) cells altogether.

So, we can sort groups up to size max.



All each **`cell`** has to do is drag heavy items backwards. In particular, as each group flows through, the *last* one out must be the heaviest in the group.

To do this, two *variables* (or *registers*) are needed: one to hold the **`largest`** item seen so far and one to hold the **`next`** item to arrive.



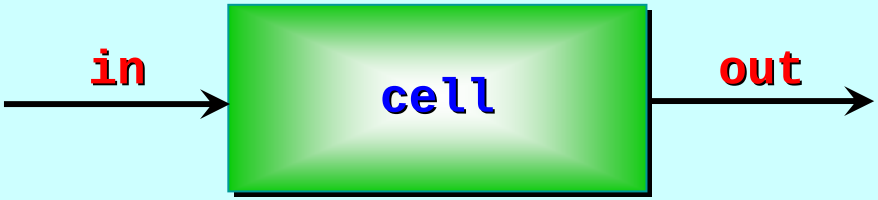
The **cell** inputs the first item of a group into **largest**.

Then, it compares each **next** item against **largest**, outputting the smaller and keeping the larger.

When the **end.marker** arrives, it just outputs the **largest** followed by that **end.marker**.

```
VAL BYTE end.marker IS 255:     -- assume > data items

PROC cell (CHAN BYTE in?, out!)
  WHILE TRUE
    BYTE largest:
    SEQ
      in ? largest
      WHILE largest <> end.marker
        BYTE next:
        SEQ
          in ? next
          IF                    -- output smaller, keep larger
            largest >= next
              out ! next
            TRUE                -- i.e. largest < next
              SEQ
                out ! largest
                largest := next
      out ! end.marker
:
```



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    SEQ
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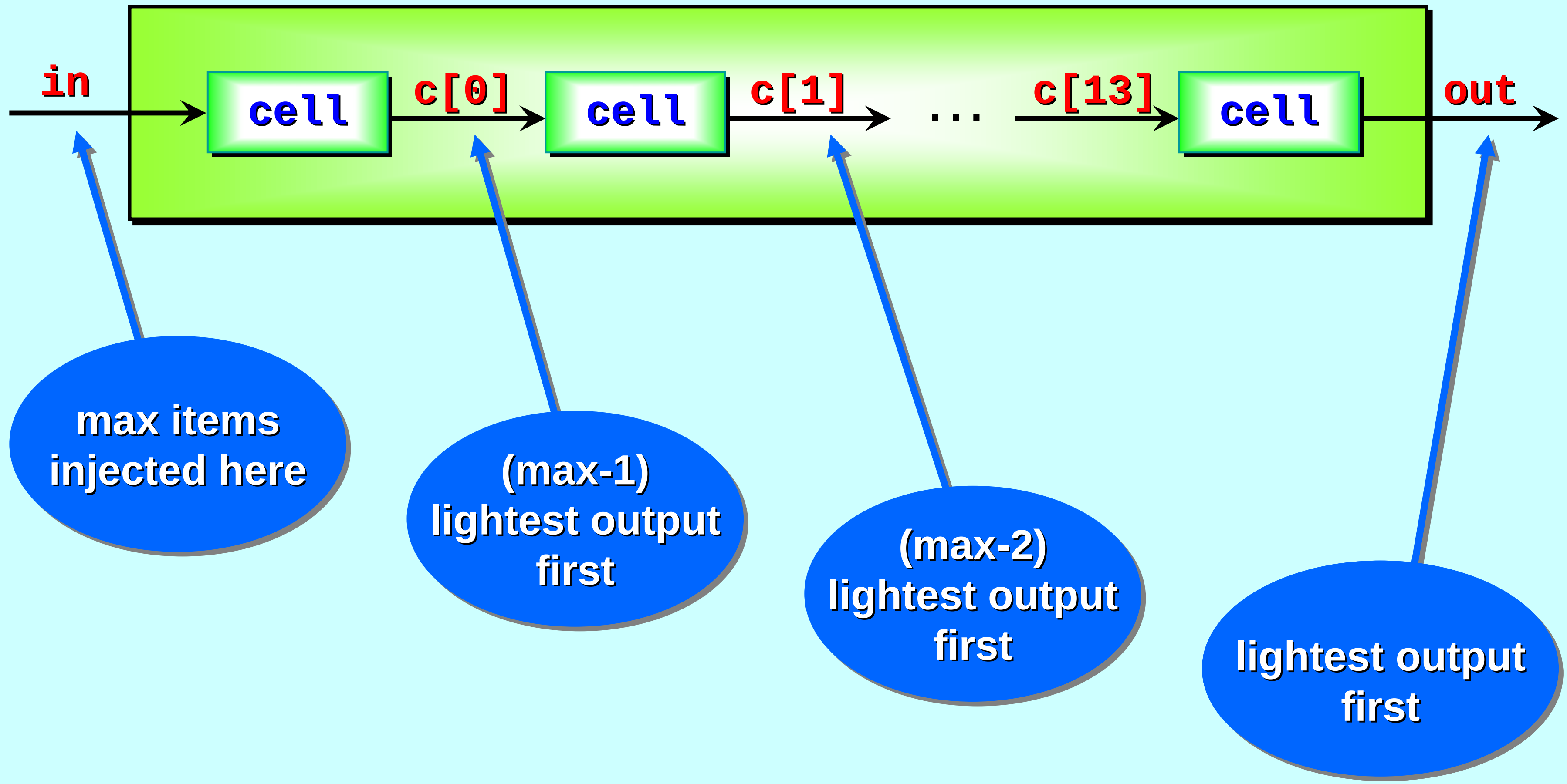
      WHILE largest <> end.marker
        BYTE next:
        SEQ
          in ? next
          IF            -- output smaller, keep larger
            largest >= next
              out ! next
            TRUE        -- i.e. largest < next
              SEQ
                out ! largest
                largest := next
      out ! end.marker
:
```

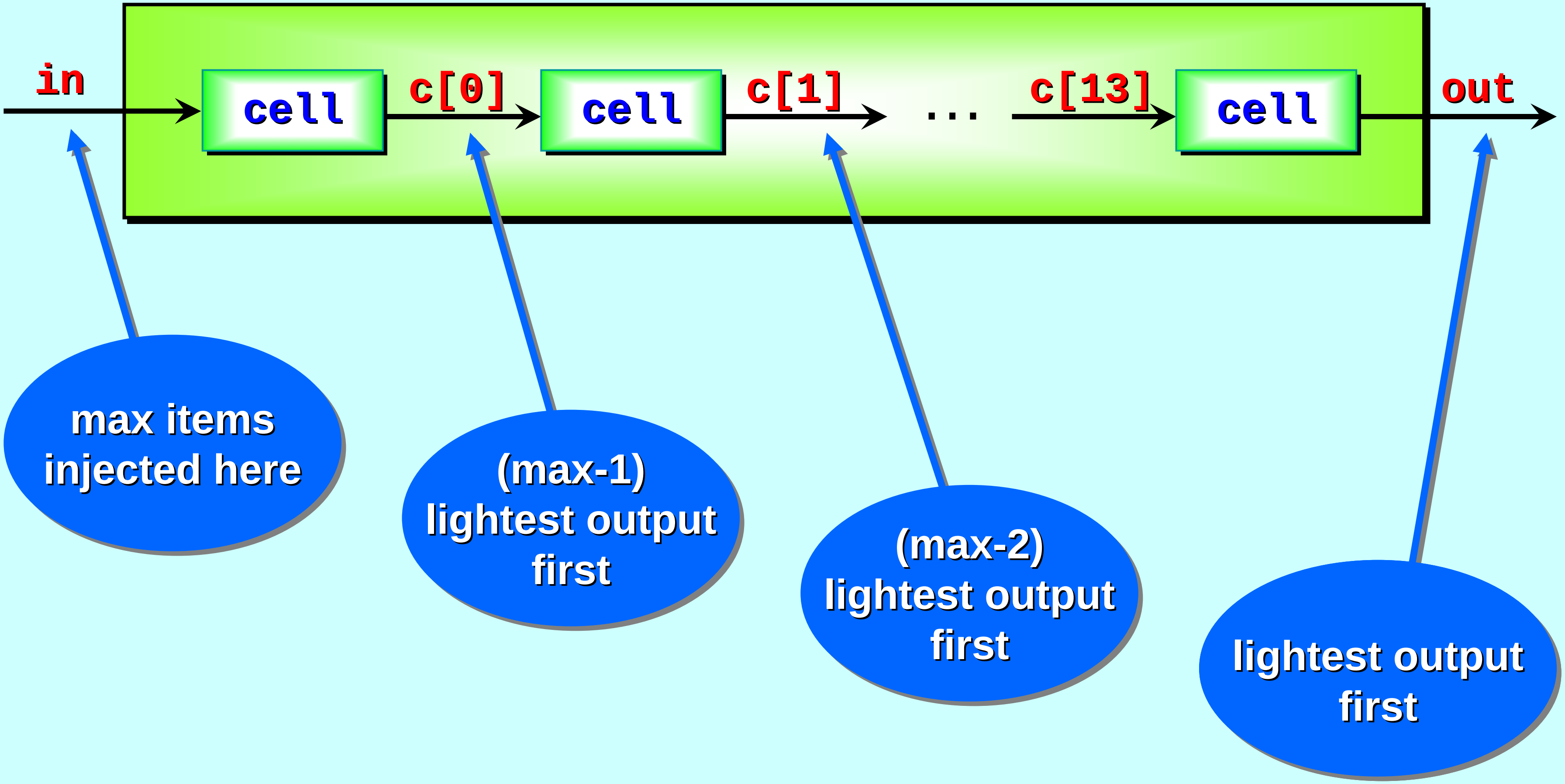
Note: this algorithm requires a potential data item (**255**) reserved for the **end.marker**. This constraint can be removed – later.

`VAL INT max IS 16:`



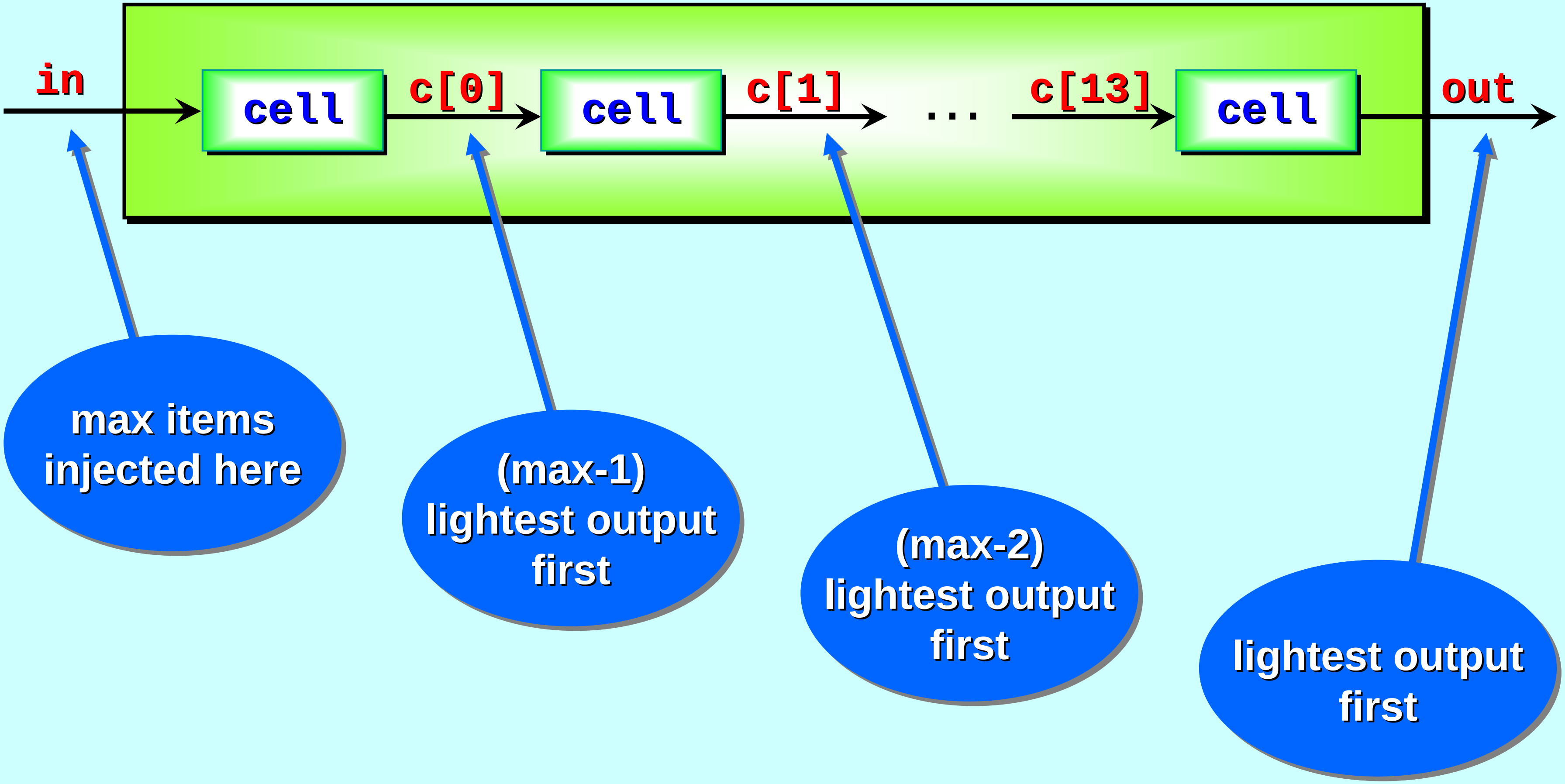
Each `cell` holds back largest item it sees, so …

```
VAL INT max IS 16:
```



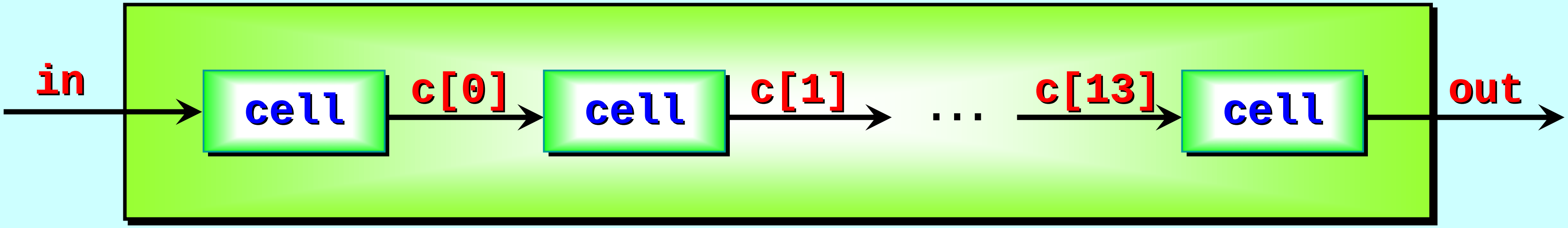
As the **`end.marker`** flows through, it pushes out the heaviest item, which pushes out the next heaviest, etc…

```
VAL INT max IS 16:
```



The group, therefore, flows out in ascending sorted order. ☺

`VAL INT max IS 16:`

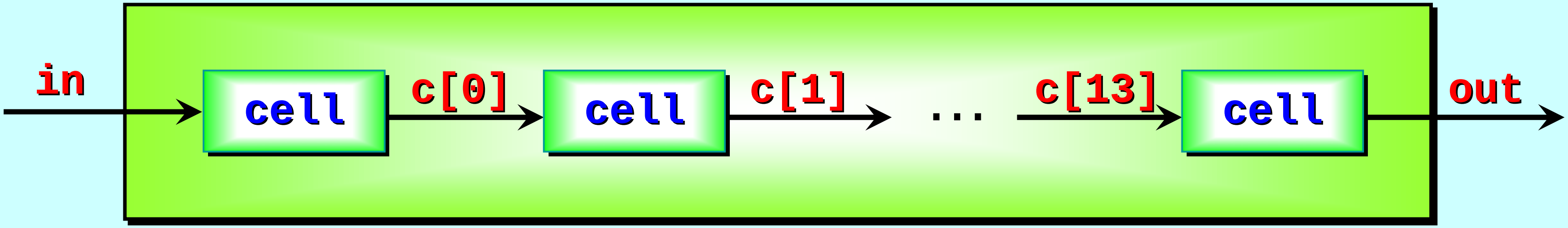


If the cells are implemented on separate pieces of silicon *(i.e. we have a physically parallel engine)*, the speed at which data flows through is the *slowest* of:

- the speed at which data is offered;
- the cycle speed for each cell;
- the inter-cell communication speed.

The speed is independent of the number of cells – which means that it is independent of the number of items being sorted. We have an *O(n)* sorting engine: **`sort.pump`**. ☺ ☺ ☺

```
VAL INT max IS 16:
```

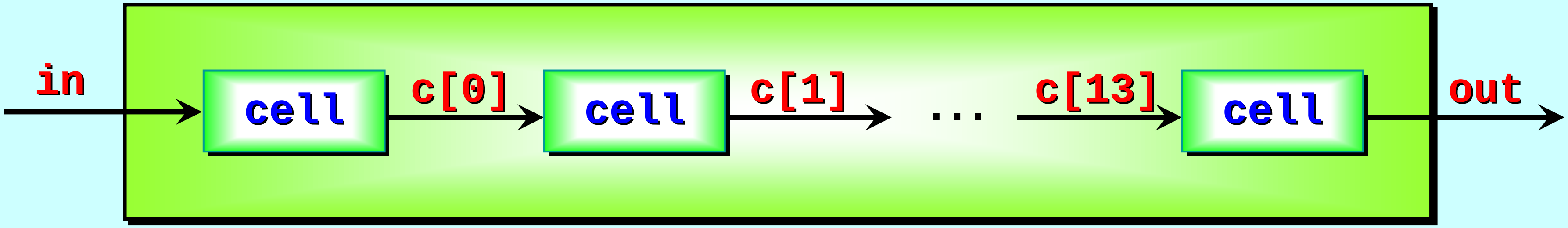


In fact, **`sort.pump`** is a parallel version of *bubble-sort*, one of the simplest known sorting algorithms. Its performance on a *serial* processor is *O(n*n)*, which is poor compared to more complex sorts (such as *quick-sort*, which is *O(n*log(n))*).

If data is supplied in *O(n)* time (as in the above, where the numbers are supplied *one-at-a-time*), then a processing complexity of *O(n)* cannot be beat!

Lesson: when considering a *parallel* design, don't start from the most efficient known *serial* algorithm – it's probably optimised the wrong way. *Rethink – look for the simplest approach.*

```
VAL INT max IS 16:
```



Note: the capacity of **`sort.pump`** is *(2*max - 2)* items, each **`cell`** holding *2* of them.

So, **`sort.pump`** *can be* processing (parts of) two or three groups (up to *max* size) at the same time.

It will only operate efficiently so long as there is a continuous supply of groups to be sorted.

For example, if only one group were pushed through, only half the **`cell`**s would ever be operating at the same time.

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The **SORT PUMP** …

Component testing …

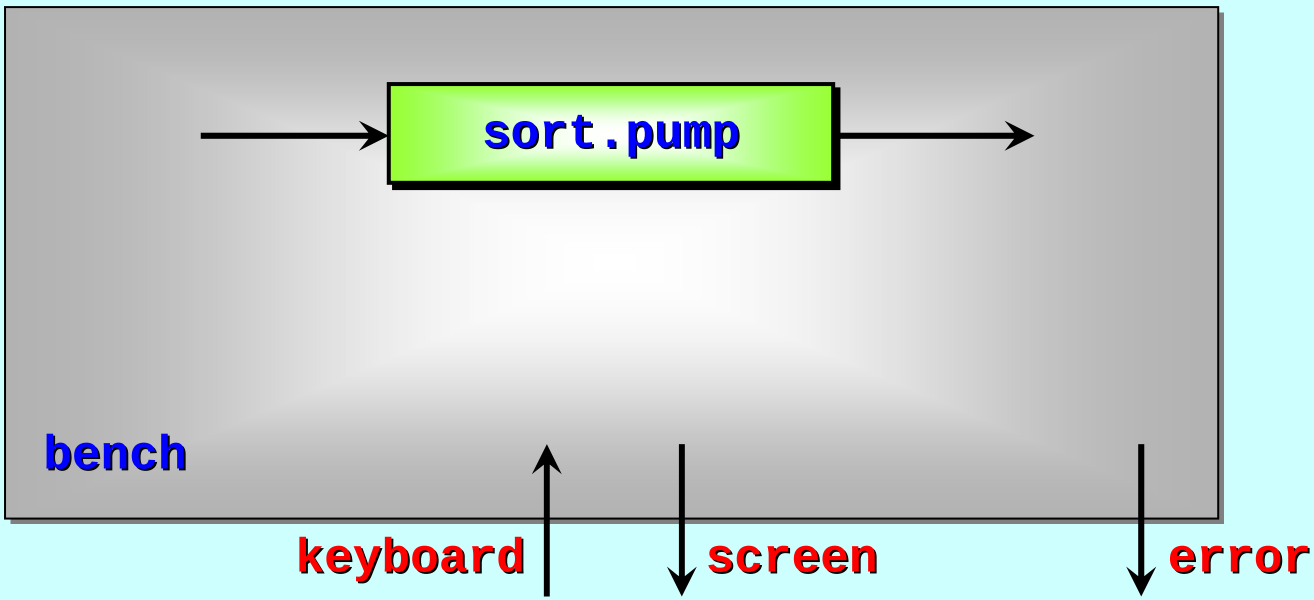
Stateless components …

The **SORT GRID** …

Replicated **IF** …

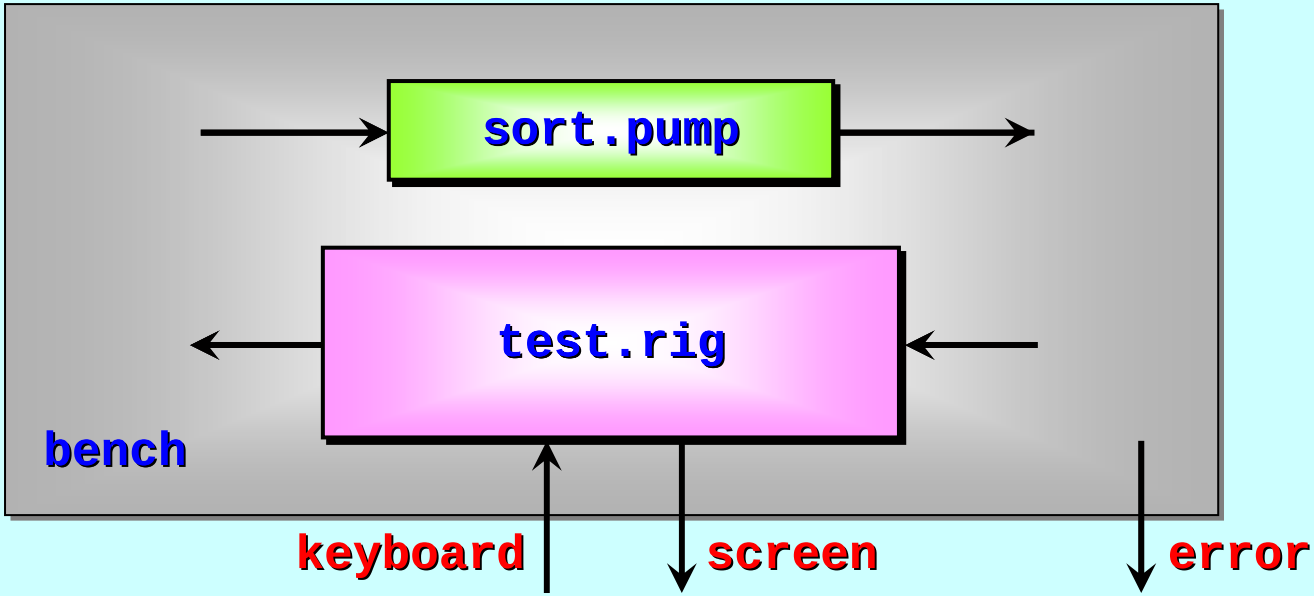
Replicator **STEP** sizes …

Component Testing



1) Place component (e.g. **`sort.pump`**) on **`bench`**.

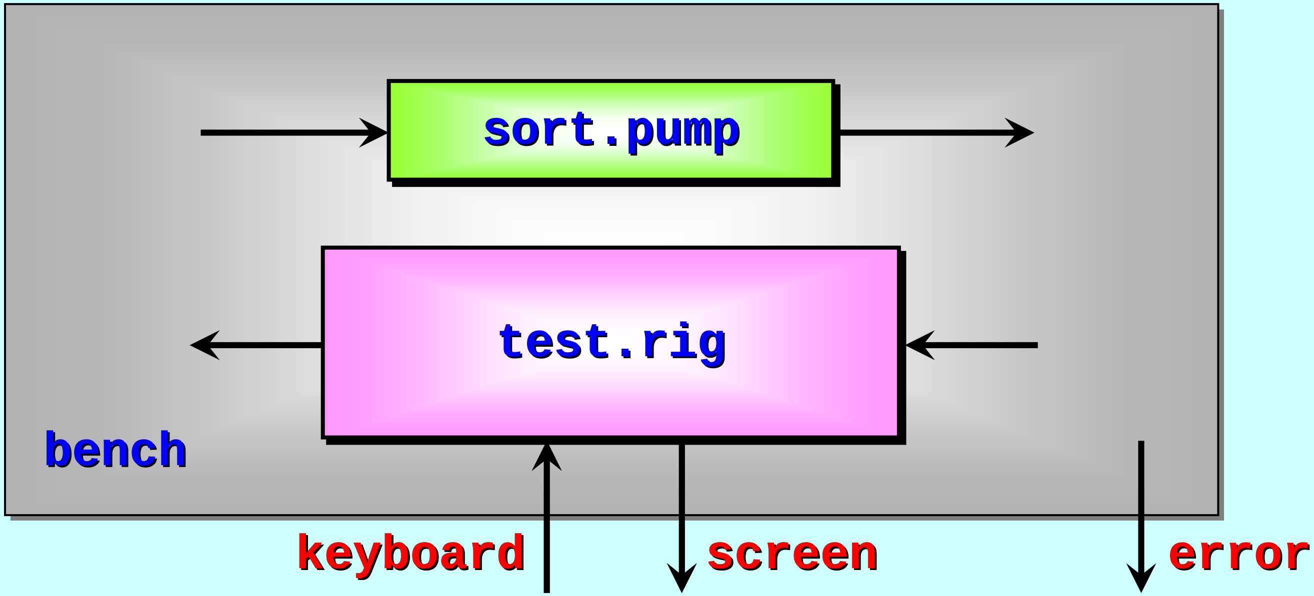
Component Testing



1) Place component (e.g. **`sort.pump`**) on **`bench`**.

2) Design **`test.rig`** through which we can interact meaningfully with component.

Component Testing



1) Place component (e.g. **sort.pump**) on **bench**.

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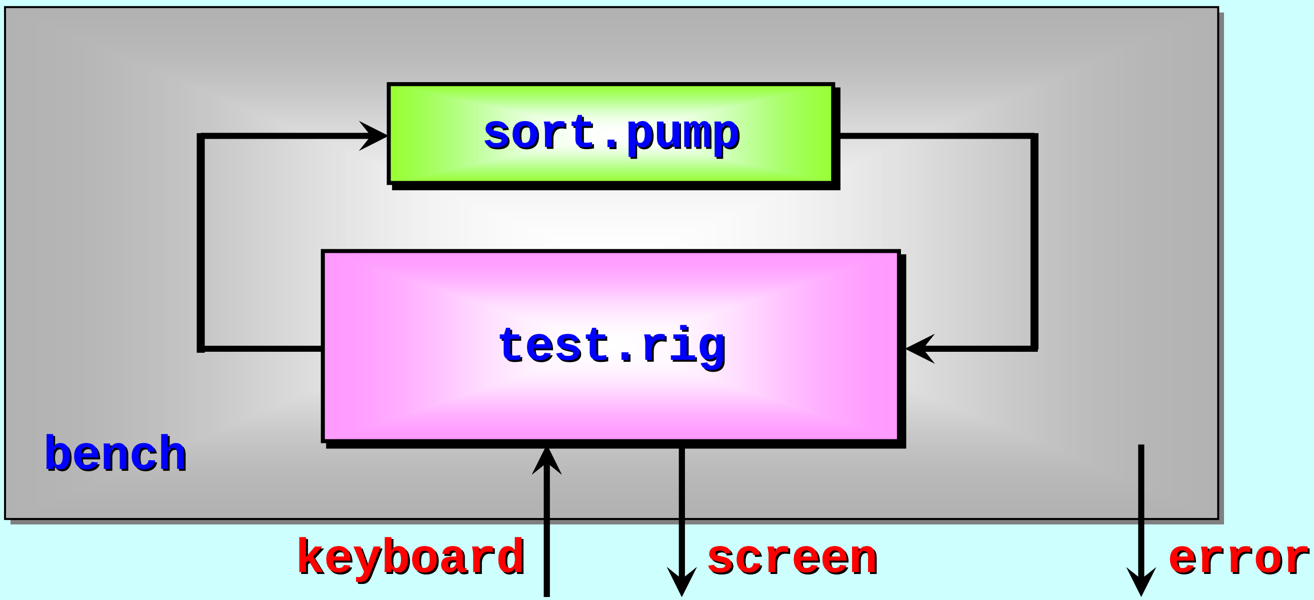
3) Wire it up and start experimenting …

Component Testing



1) Place component (e.g. **sort.pump**) on **bench**.

2) Design **test.rig** through which we can interact meaningfully with component.

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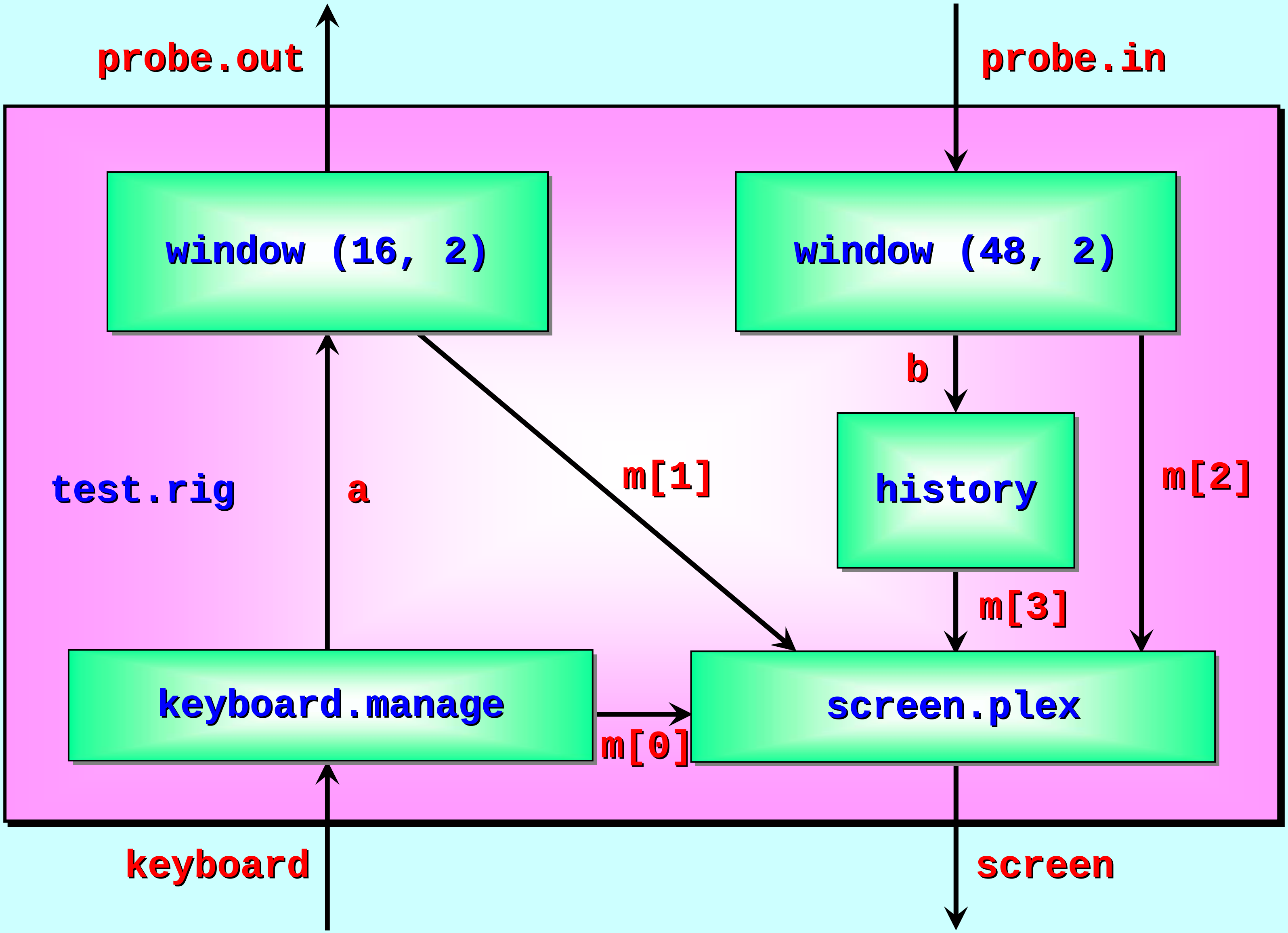
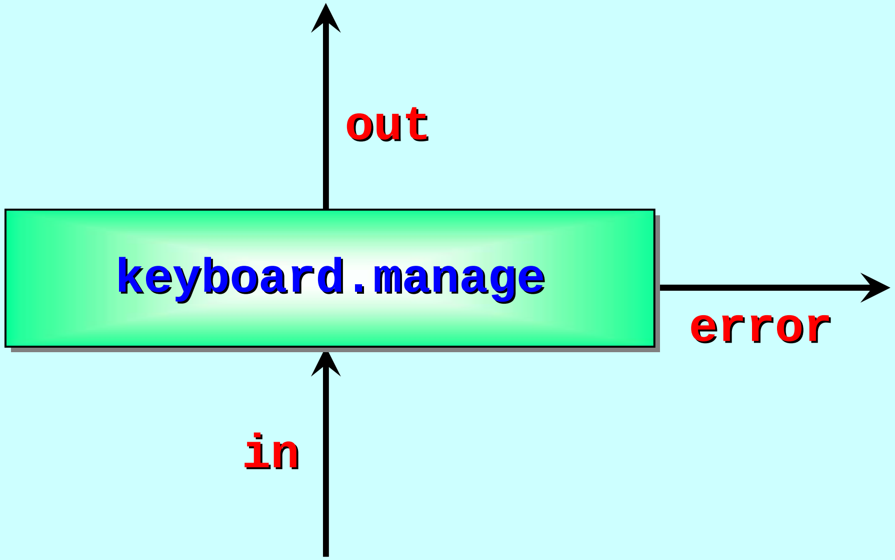
Typical Test-Rig Design

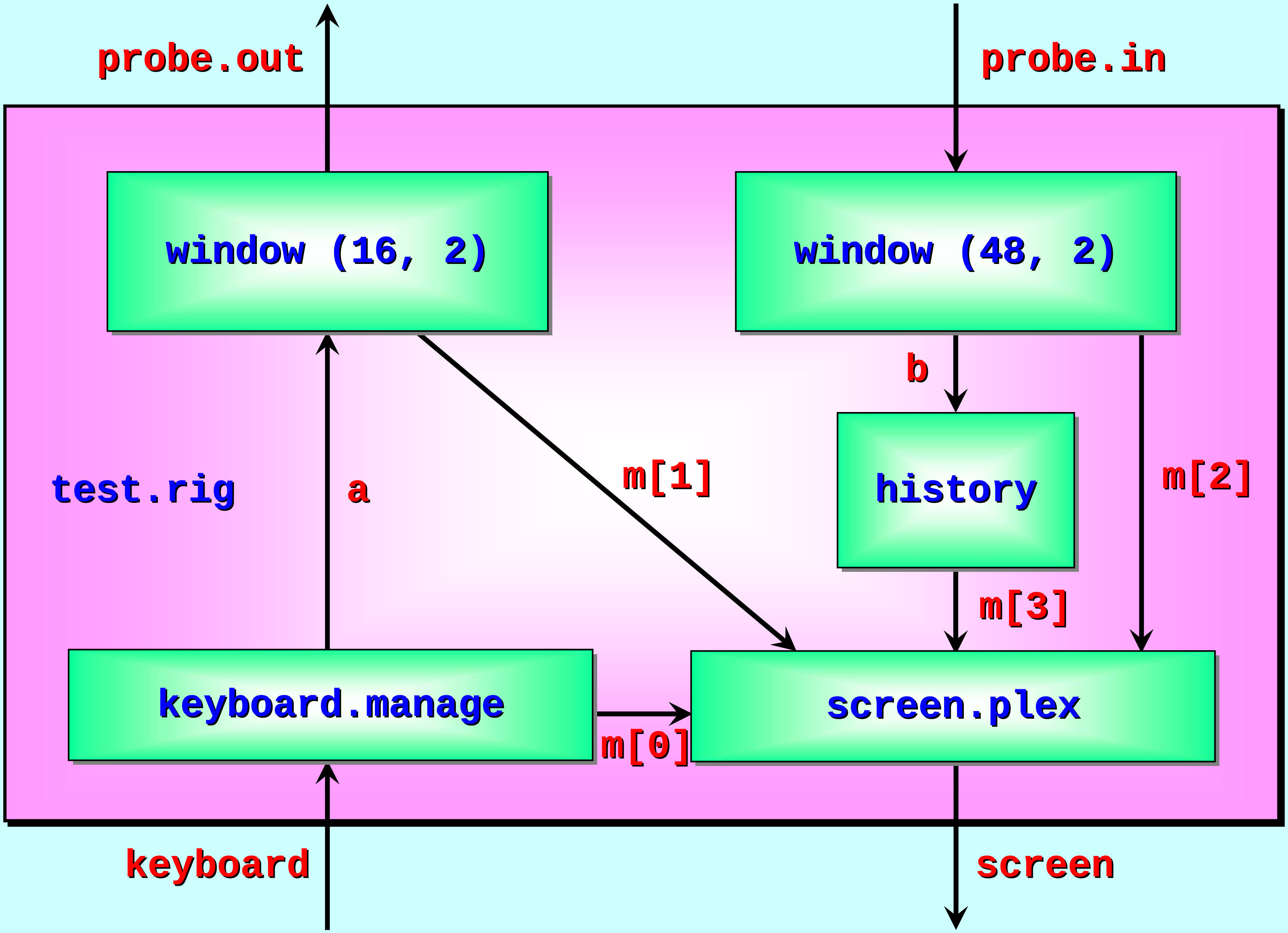


Typical Test-Rig Design

This process filters keyboard input for *'bad'* characters *(e.g. control-chars, carriage-return)*, issuing an error report for any found, and compresses / encodes *'good'* characters *(e.g. visible-chars)* for onward transmission.

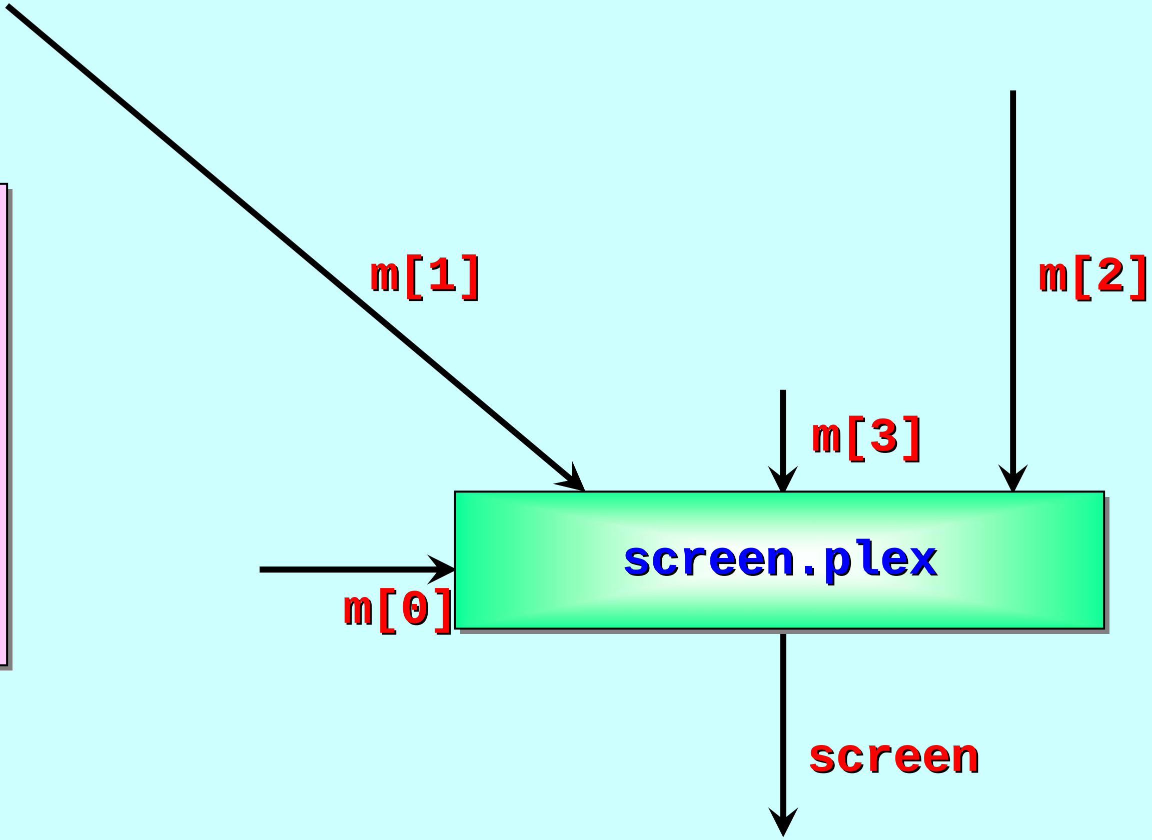


Typical Test-Rig Design

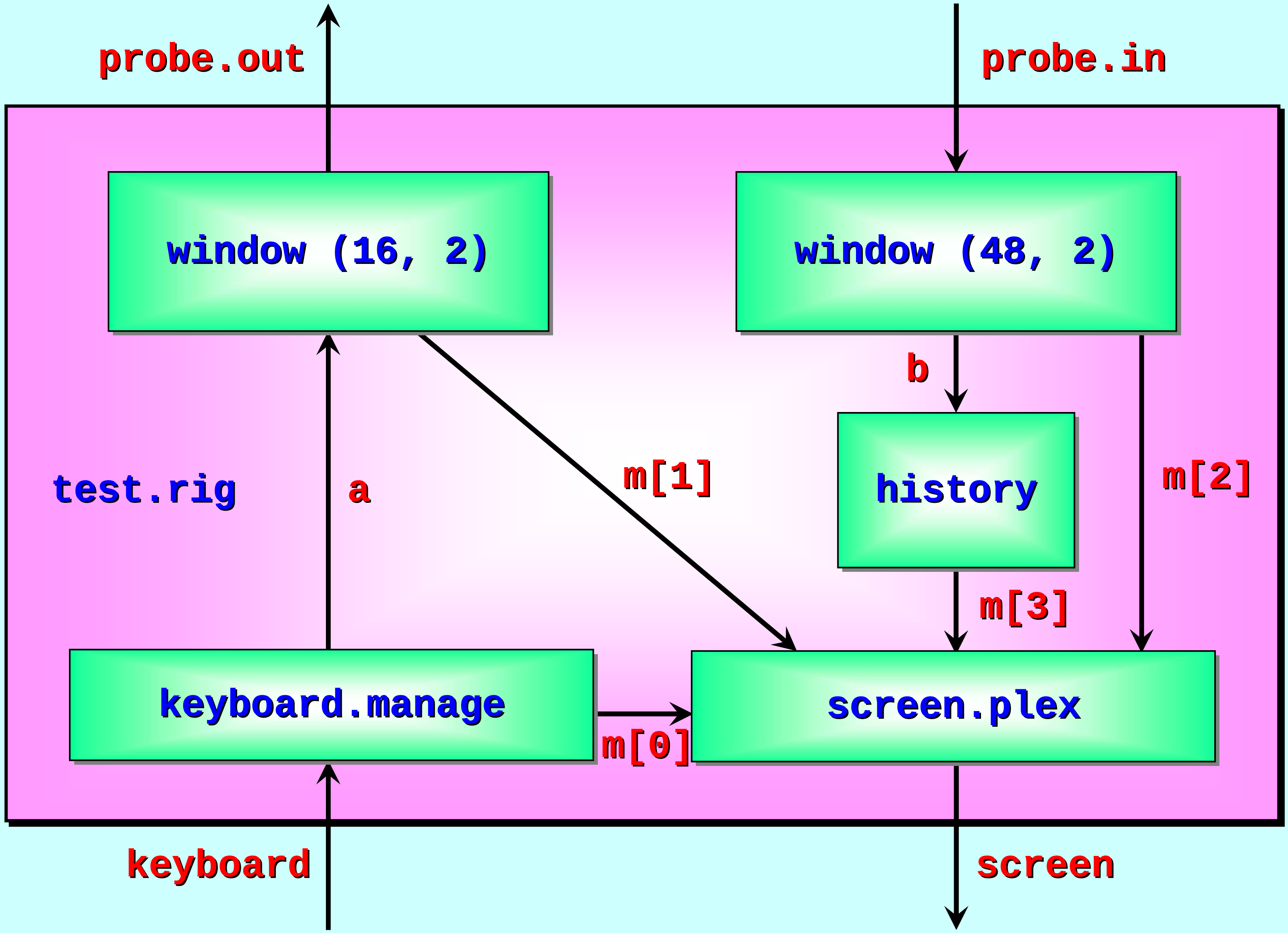


Typical Test-Rig Design

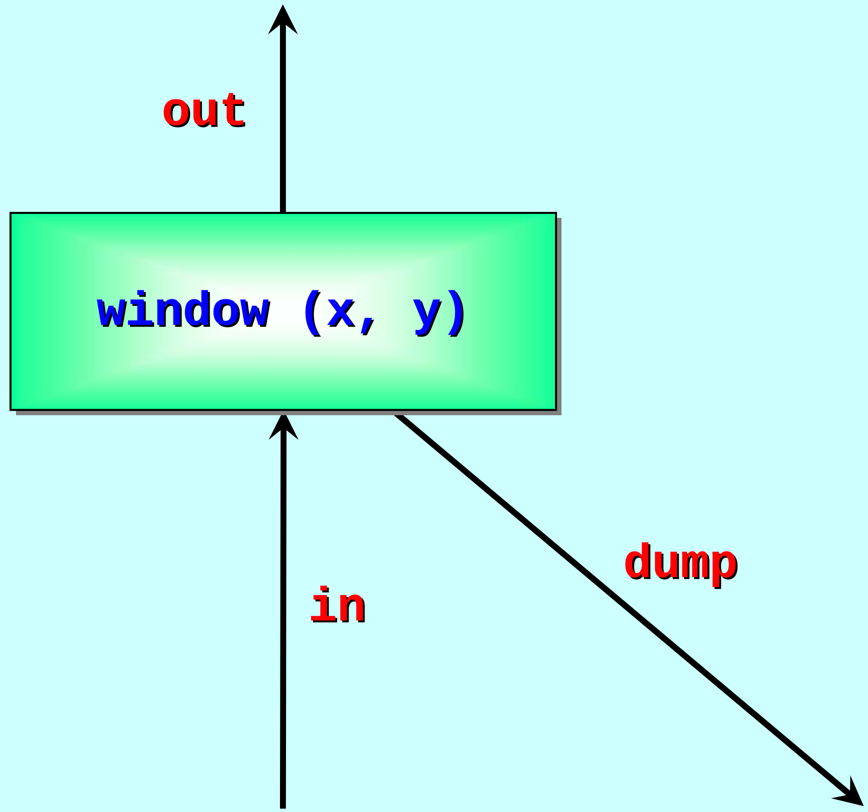
This process multiplexes an array of input streams to a single output stream.



Typical Test-Rig Design



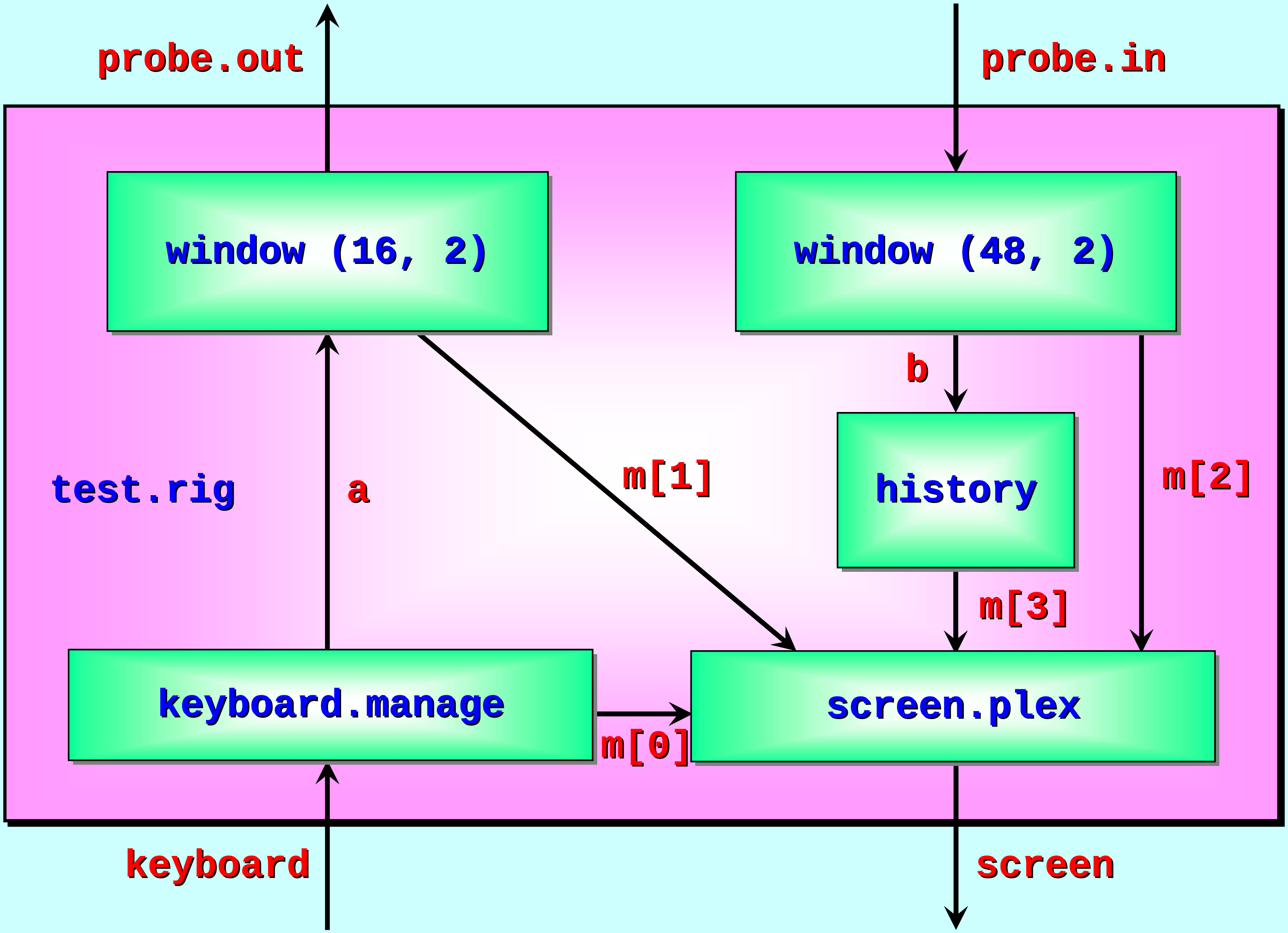
Typical Test-Rig Design



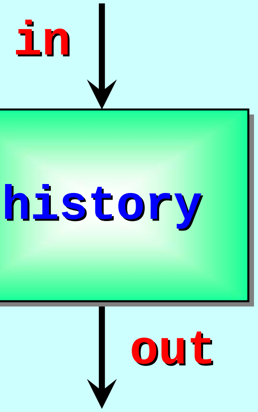
This process is a *fixed-size delay line*. Each item input pushes one item out. It holds the last **max** items received. Every cycle, it dumps its entire holding array (with screen position control-chars). This lets us see what's in the data stream.

(x, y) specifies coordinates defining the start position on the screen for the **dump** items.

Typical Test-Rig Design



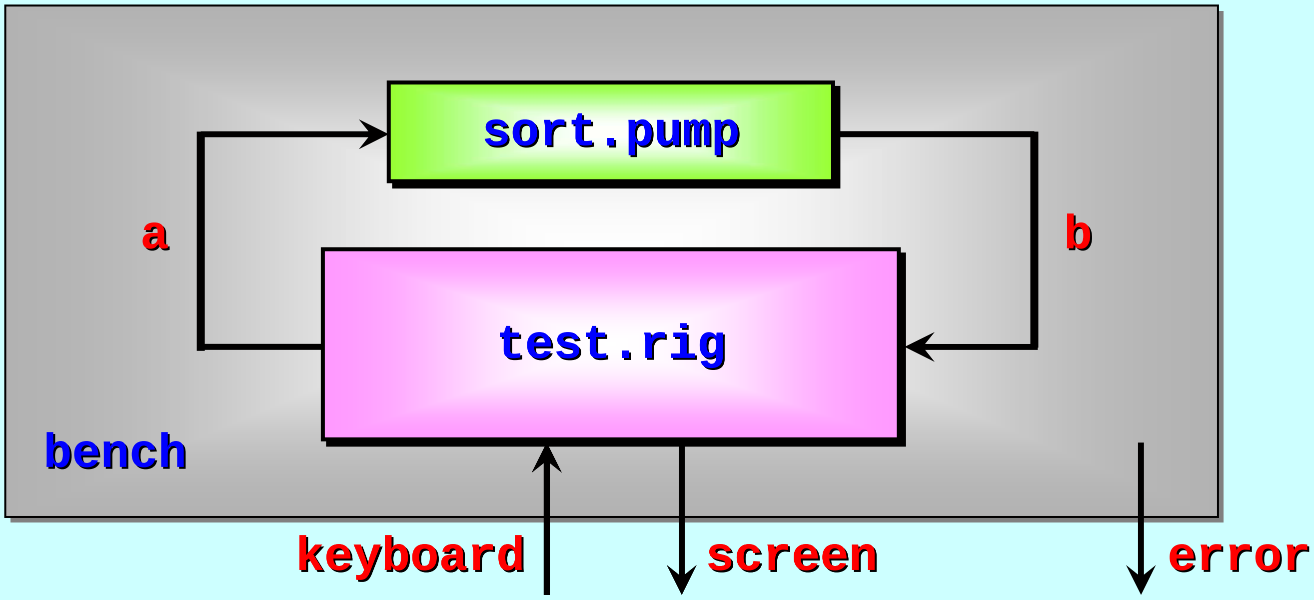
Typical Test-Rig Design



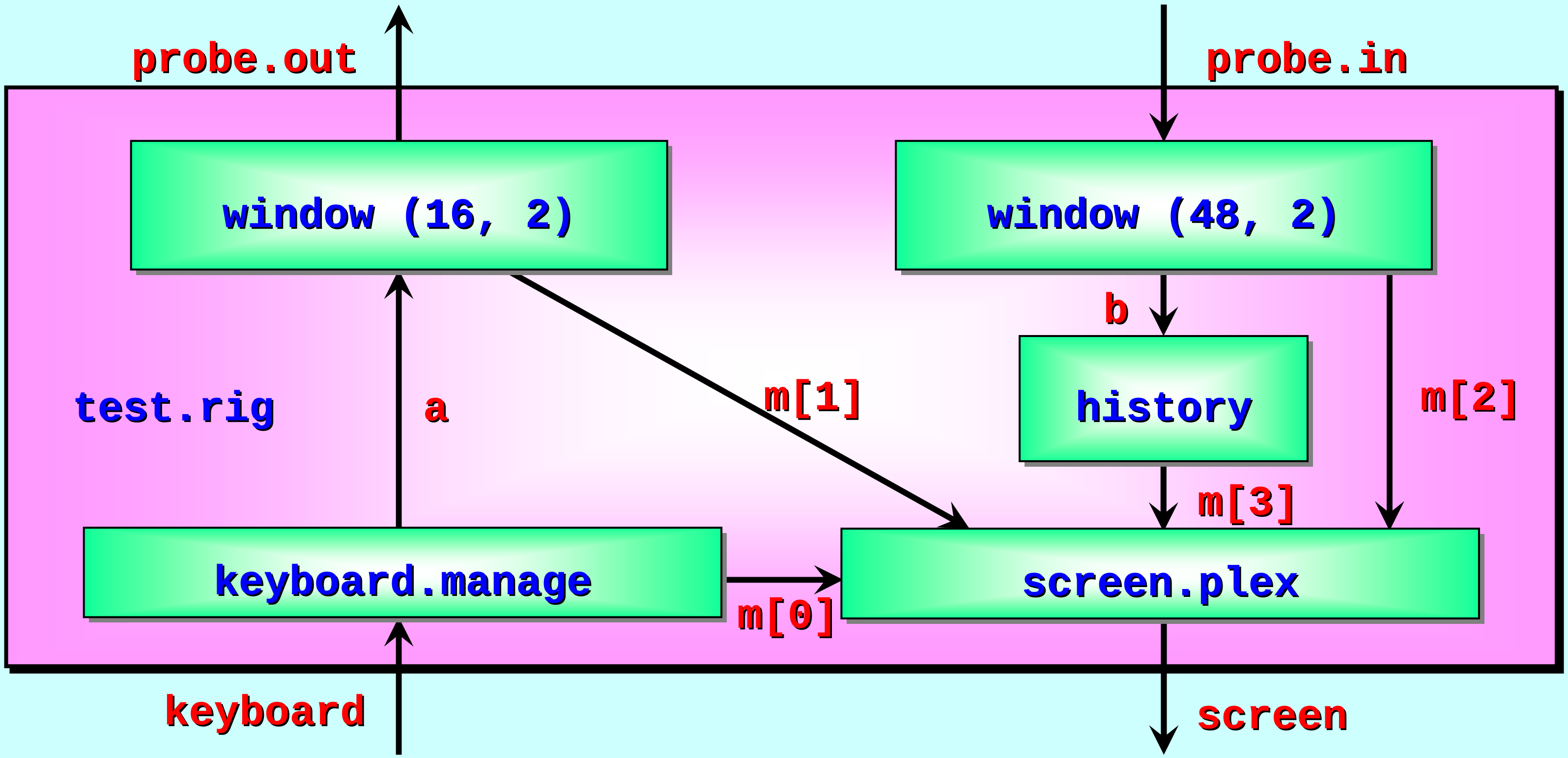
This process lays out a *history* of the items received. It uses the bottom two-thirds of the screen.

Design Guidelines

- Don't try to cram too much functionality into any process: One function ⇔ One process
- Multiple functions ⇔ Multiple processes
- Each process is programmed from its own point-of-view. Think of each process as an independent *serial* program, with a variety of input and output channels.
- *Concurrency then makes design simple!* ☺ ☺ ☺
- Try to build that **`test.rig`** as a *single serial* process and we will get a mess … ☹ ☹ ☹

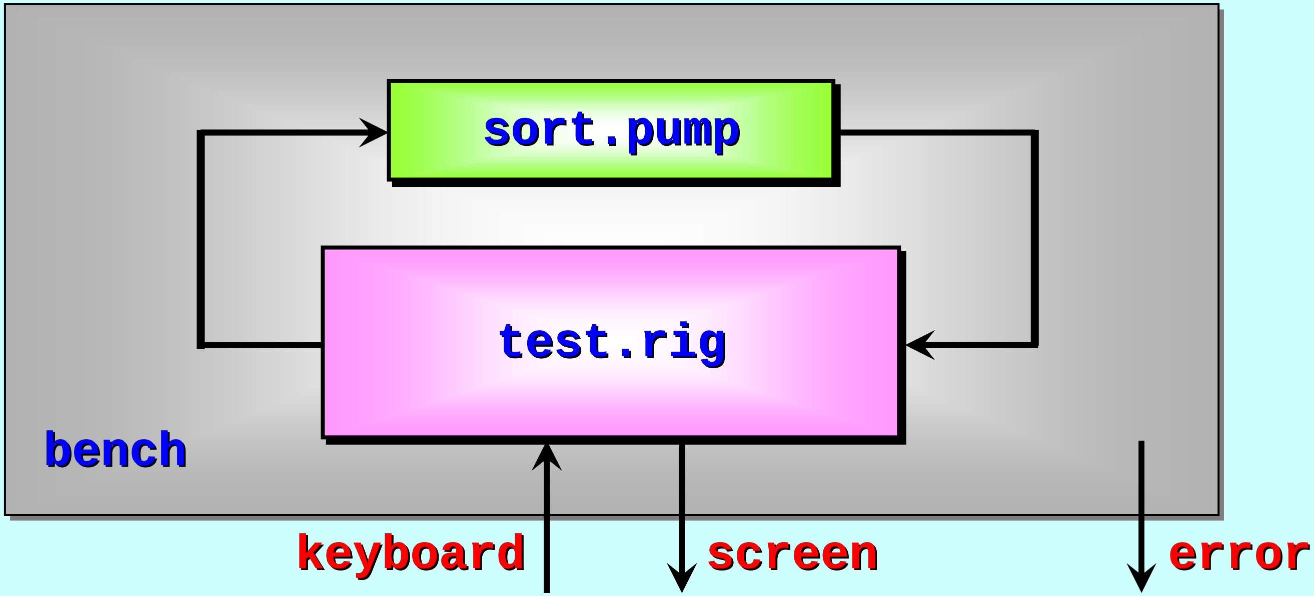



```
PROC bench (CHAN BYTE keyboard?, screen!, error!)
  CHAN BYTE a, b:
  PAR
    sort.pump (a?, b!)
    test.rig (keyboard?, screen!, a!, b?)
:
```

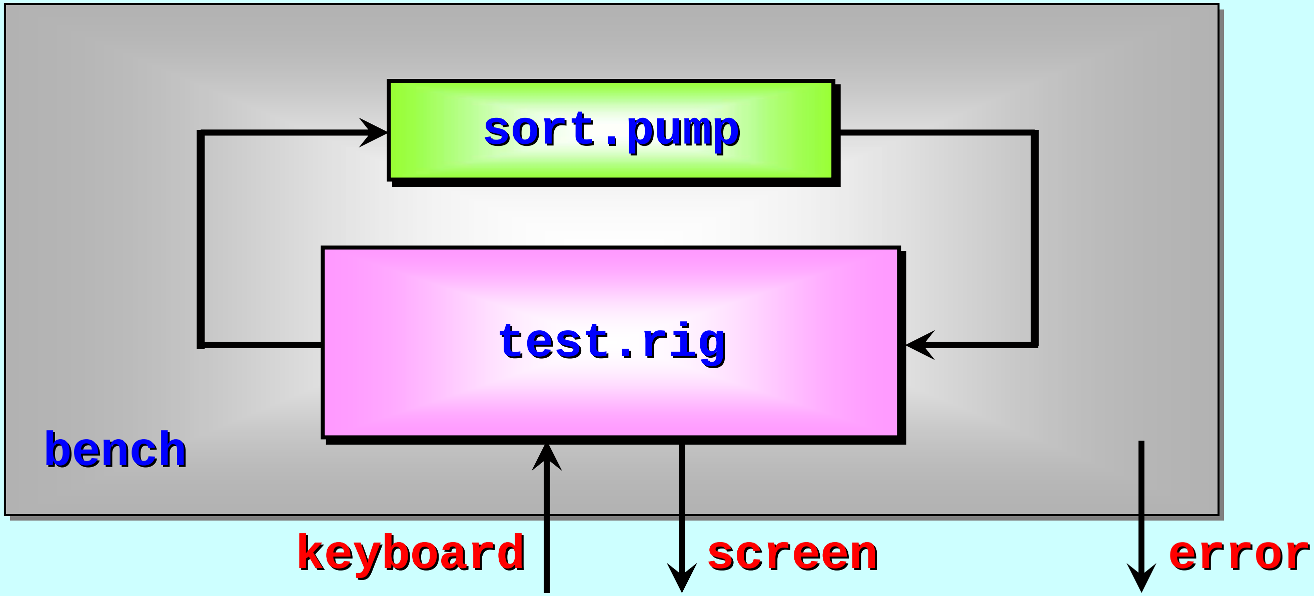



```
PROC test.rig (CHAN BYTE keyboard?, screen!, probe.out!, probe.in?)
  CHAN BYTE a, b:
  [4]CHAN BYTE m:
  PAR
    keyboard.manage (keyboard?, a!, m[0]!)
    window (16, 2, a?, probe.out!, m[1]!)  -- (16, 2) => top-left
    window (48, 2, probe.in?, b!, m[2]!)   -- (48, 2) => top-right
    history (b?, m[3]!)
    screen.plex (m?, out!)
:
```

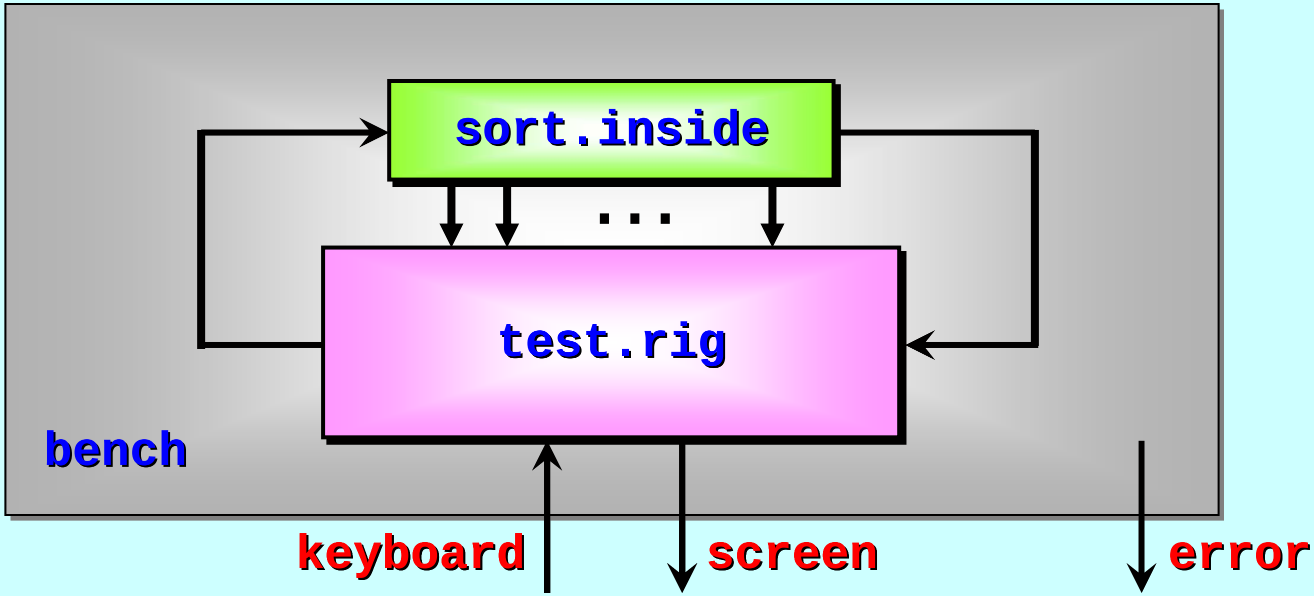
But … what if we want to see what's going on *inside* the **sort.pump**?



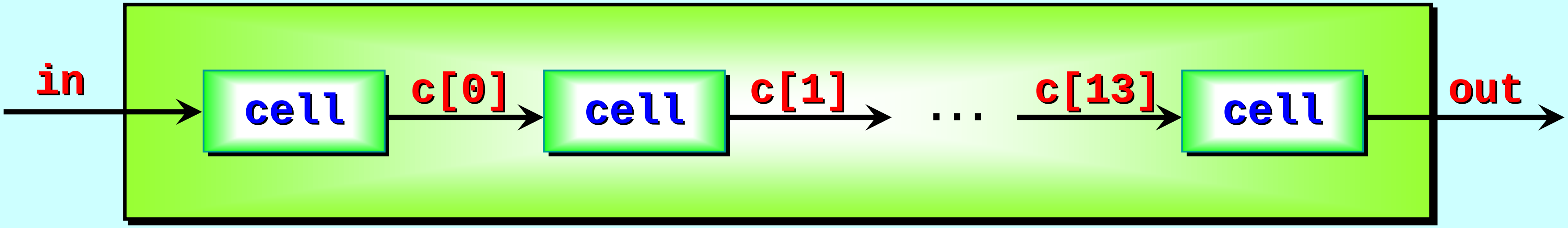
As things stand, we can’t see inside the **cell** processes in the pump.



We need to wire up the **cell**s to report their changing states.



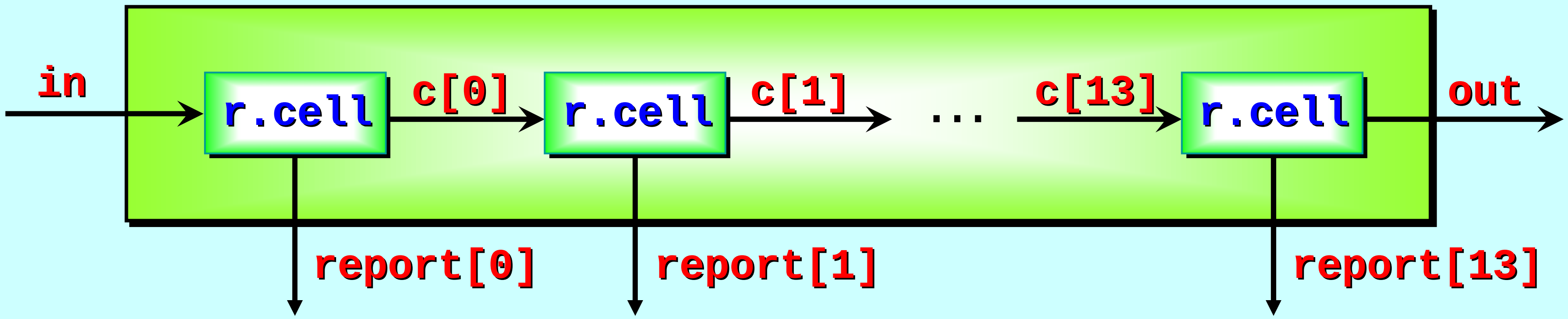
```
VAL INT max IS 16:
```




```
PROC sort.pump (CHAN BYTE in?, out)

  [max-2]CHAN BYTE c:
  PAR
    cell (in?, c[0]!)
    PAR p = 1 FOR max-3
      cell (c[p-1]?, c[p]!)
    cell (c[max-3]?, out!)
:
```

```
VAL INT max IS 16:
```



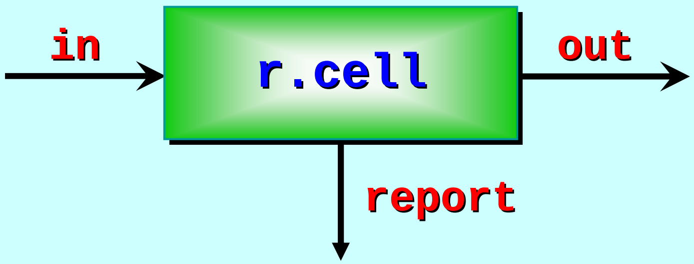

```
PROC sort.inside (CHAN BYTE in?, out!,
                  []CHAN BYTE report!)
  [max-2]CHAN BYTE c:
  PAR
    reporting.cell (in?, report[0]!, c[0]!)
    PAR p = 1 FOR max-3
      reporting.cell (c[p-1]?, report[i]!, c[p]!)
    reporting.cell (c[max-3]?, report[max-3]!, out!)
:
```

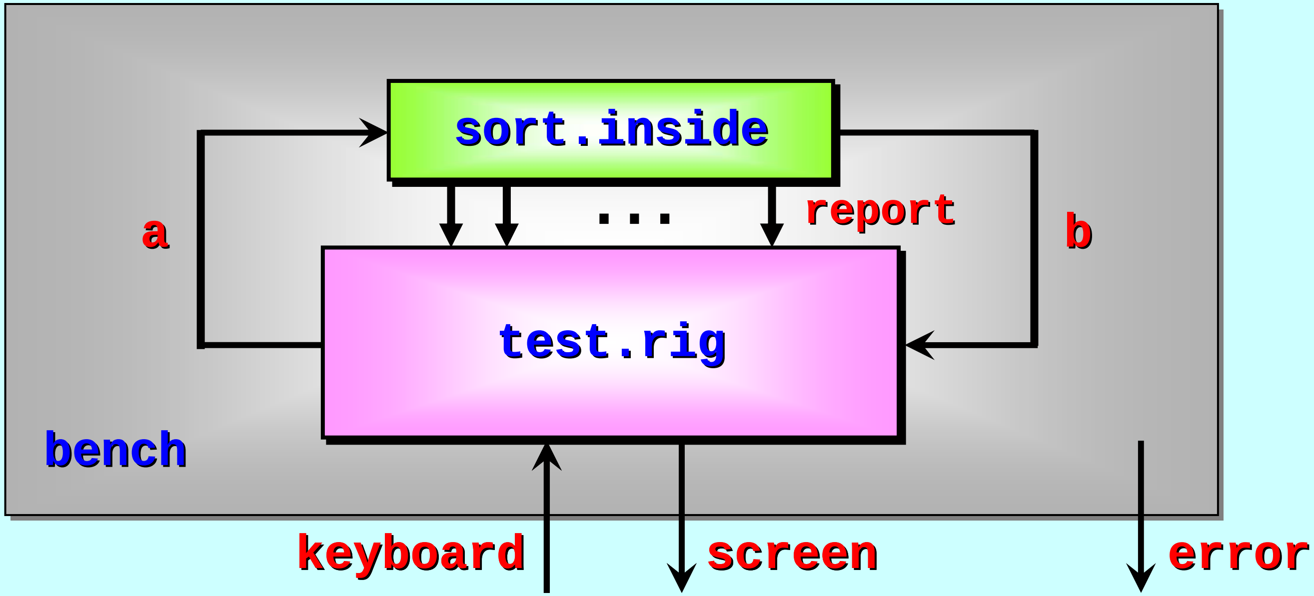
```
VAL BYTE end.marker IS 255:     -- assume > data items


PROC cell (CHAN BYTE in?, out!)
  WHILE TRUE
    BYTE largest:
    SEQ
      in ? largest
      WHILE largest <> end.marker
        BYTE next:
        SEQ
          in ? next
          IF                -- output smaller, keep larger
            largest >= next
              out ! next
            TRUE            -- i.e. largest < next
              SEQ
                out ! largest
                largest := next
      out ! end.marker
:
```

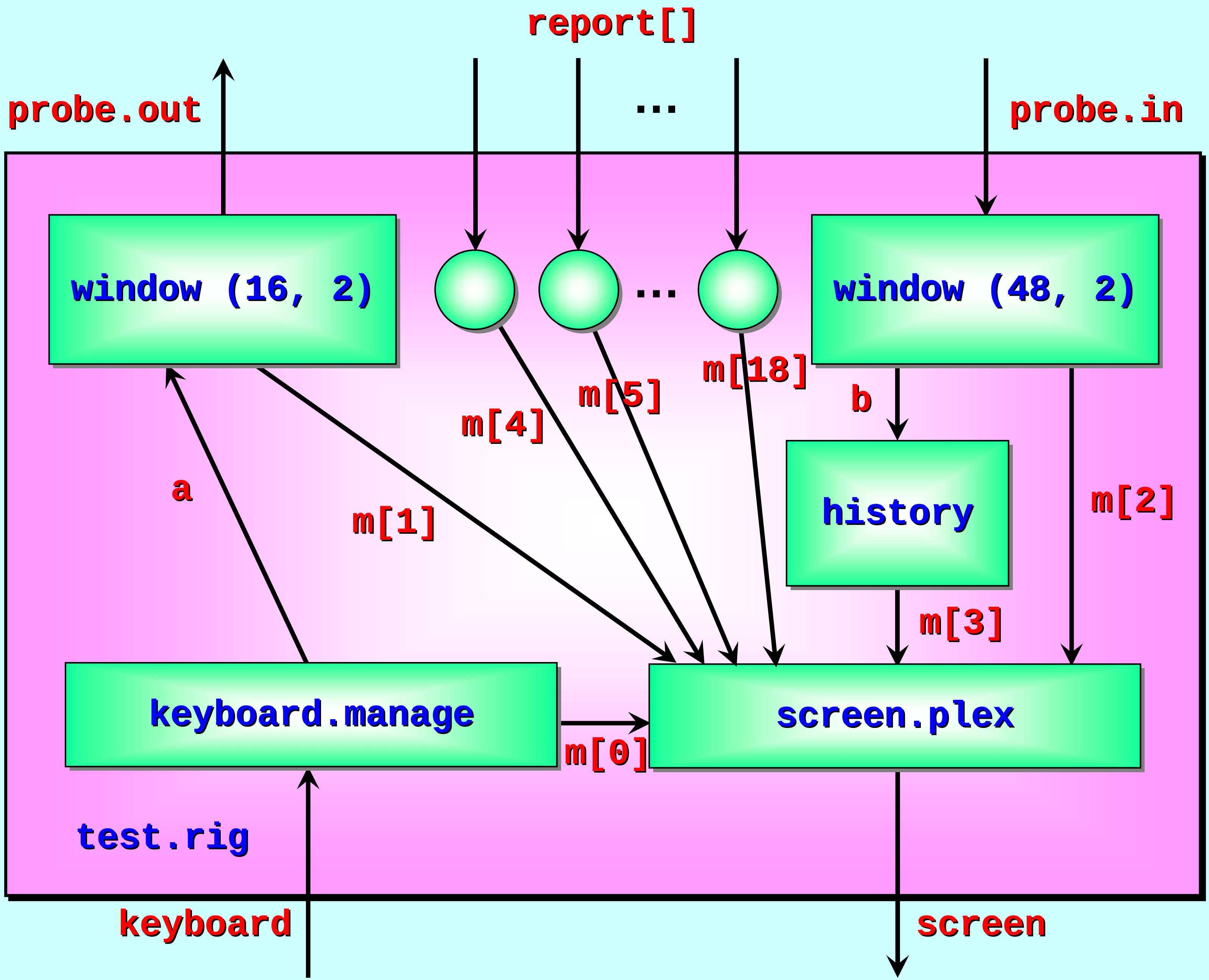
```
VAL BYTE end.marker IS 255:     -- assume > data items

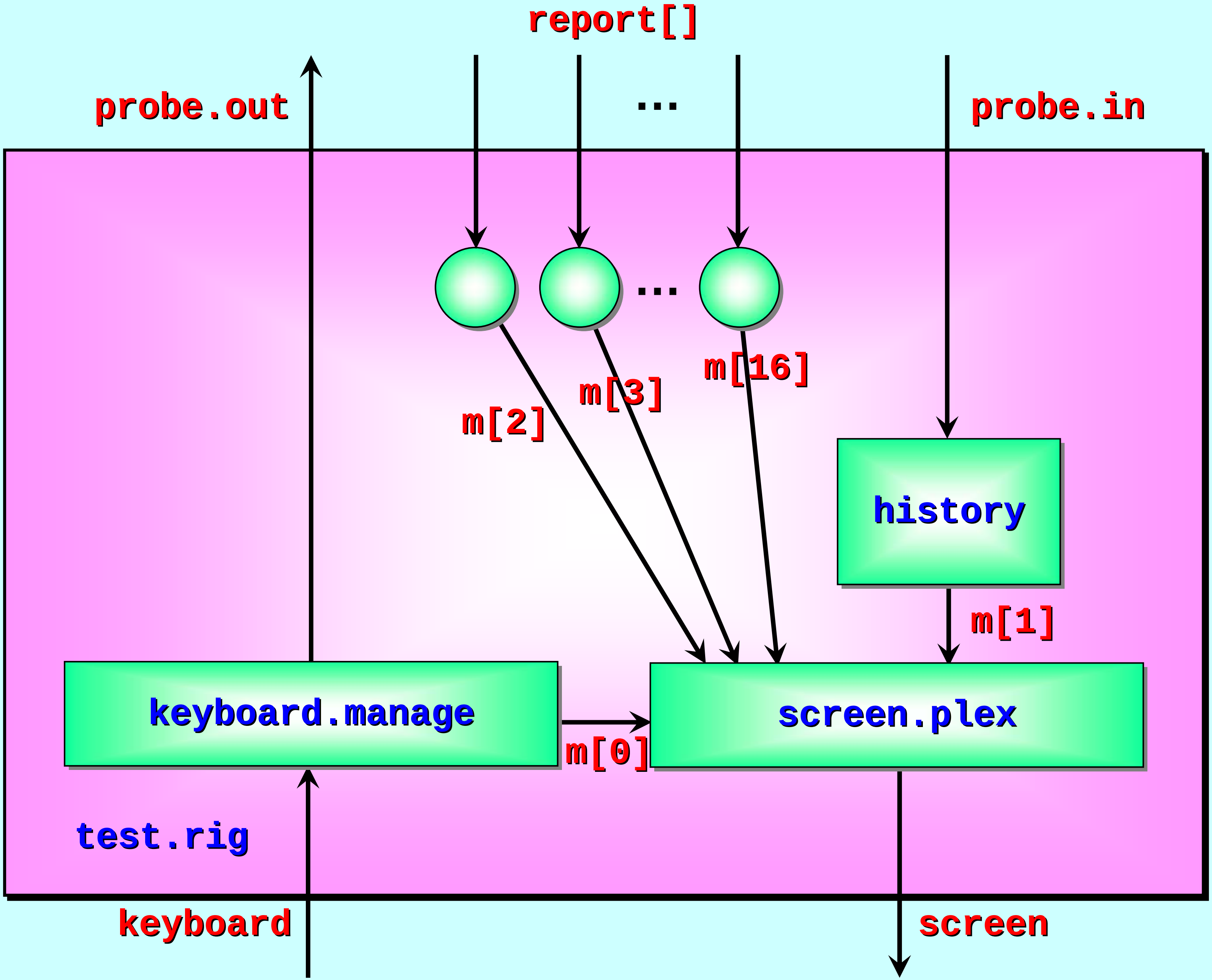

PROC reporting.cell (CHAN BYTE in?, report!, out!)
  WHILE TRUE
    BYTE largest:
    SEQ
      ...  report ! '~'; '~'
      in ? largest
      ...  report ! '~'; largest
      WHILE largest <> end.marker
        BYTE next:
        SEQ
          in ? next
          ...  report ! next; largest
          IF                -- output smaller, keep larger
            largest >= next
              out ! next
            TRUE            -- i.e. largest < next
              SEQ
                out ! largest
                largest := next
          ...  report ! '~'; largest
      out ! end.marker
:
```

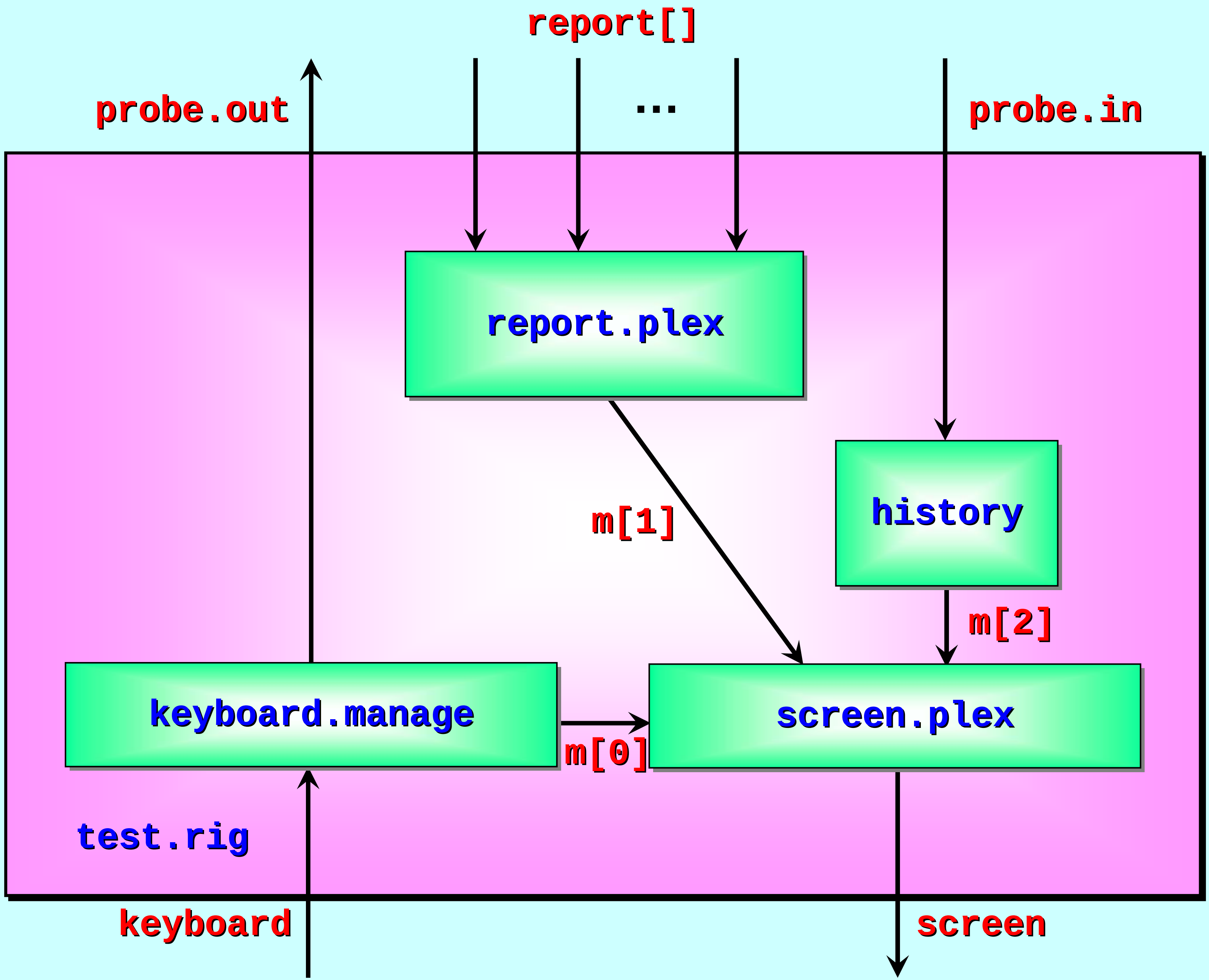


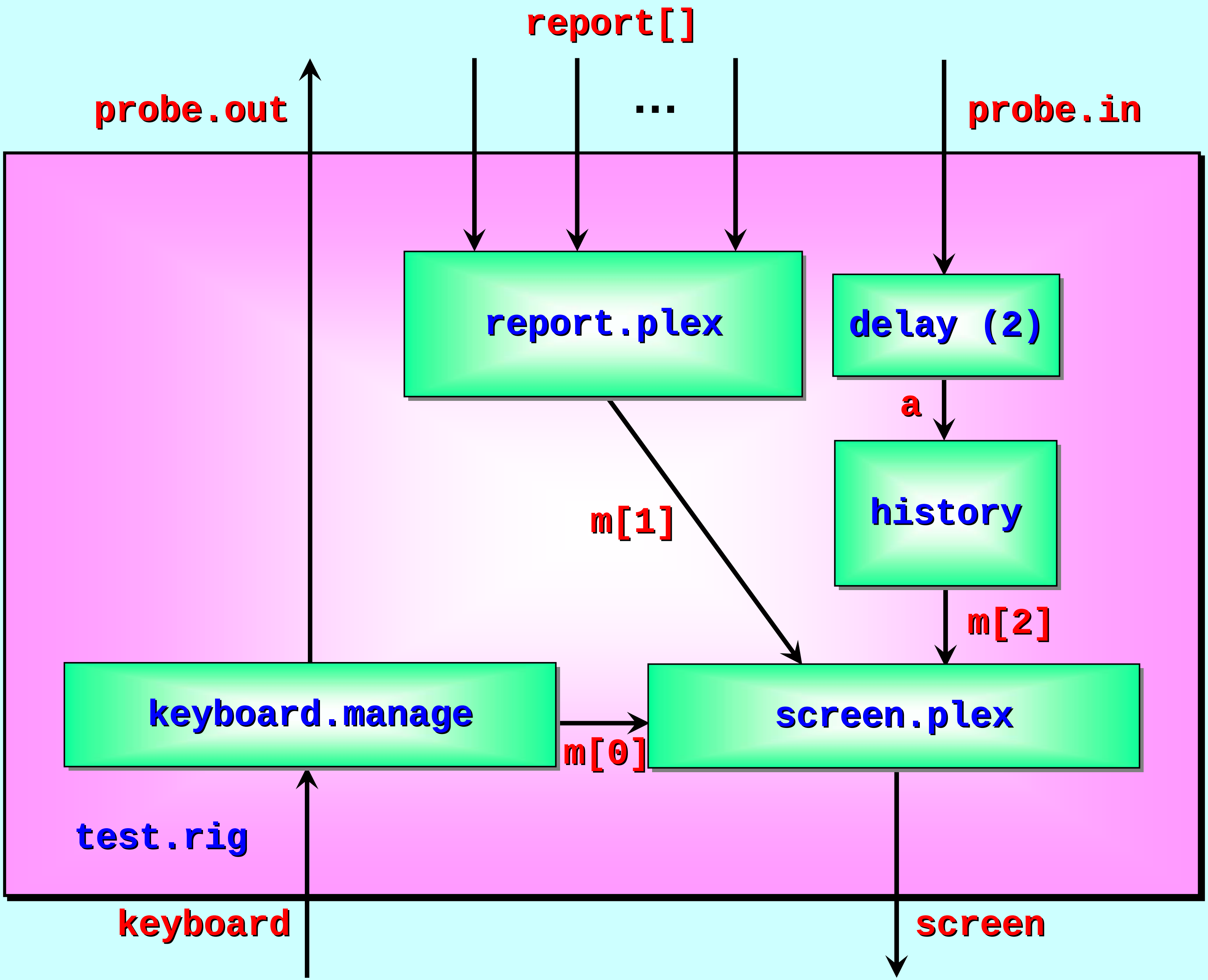



```
PROC bench (CHAN BYTE keyboard?, screen!, error!)
  CHAN BYTE a, b:
  [max-1]CHAN BYTE report:
  PAR
    sort.pump (a?, report!, b!)
    test.rig (keyboard?, screen!, a!, report?, b?)
:
```


report[]
probe.out
...
probe.in
window (16, 2)
...
window (48, 2)
m[4]
m[5]
m[18]
b
a
m[1]
history
m[2]
m[3]
keyboard.manage
screen.plex
m[0]
test.rig
keyboard
screen


report[]
probe.out
...
probe.in
...
m[2]
m[3]
m[16]
history
m[1]
keyboard.manage
m[0]
screen.plex
test.rig
keyboard
screen


report[]
probe.out
...
probe.in
report.plex
m[1]
history
m[2]
keyboard.manage
m[0]
screen.plex
test.rig
keyboard
screen


report[]
probe.out
...
probe.in
report.plex
delay (2)
a
history
m[1]
m[2]
keyboard.manage
screen.plex
m[0]
test.rig
keyboard
screen

Replicators *(components and test-rigs)*

Replicated **PAR** and **SEQ** ...

The **SORT PUMP** …

Component testing …

Stateless components …

The **SORT GRID** …

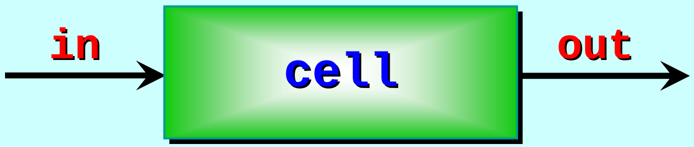
Replicated **IF** …

Replicator **STEP** sizes …

Let's simplify the logic within a **cell** process ...

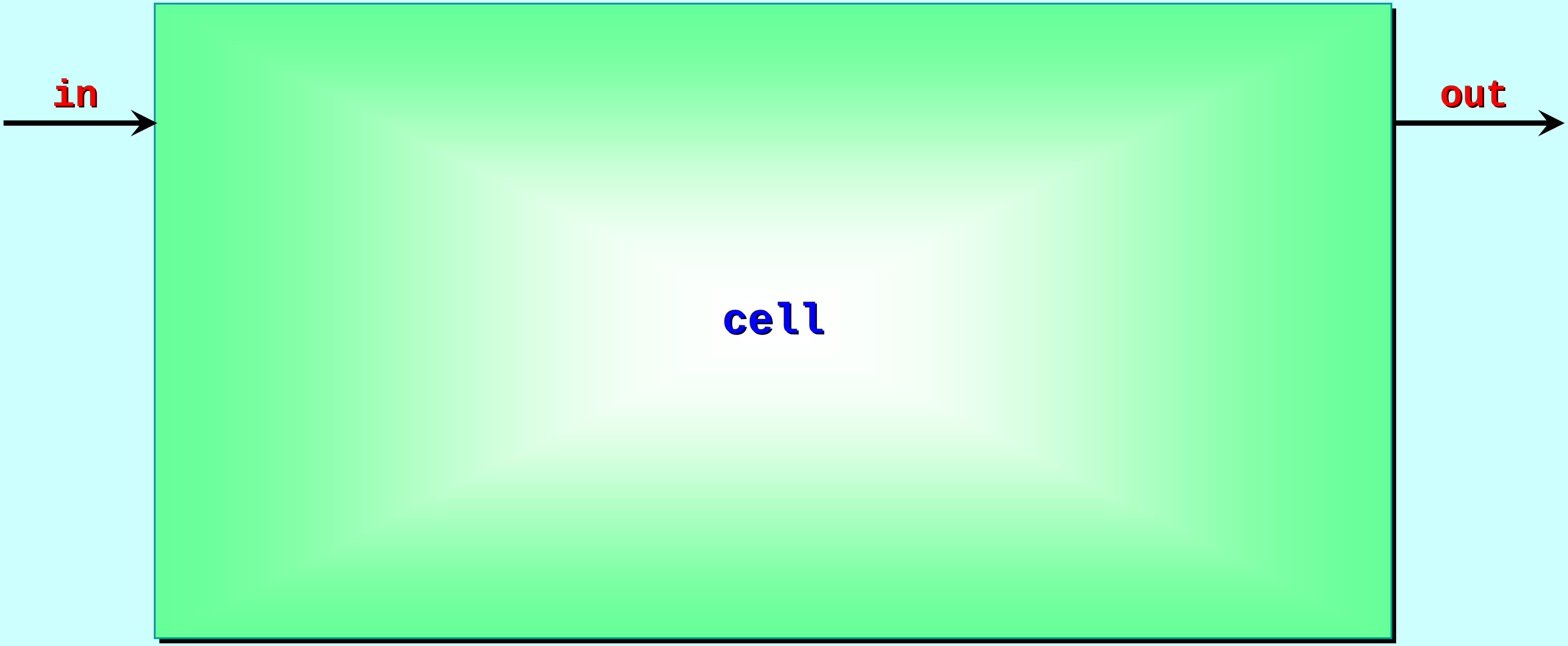
```
VAL BYTE end.marker IS 255:     -- assume > data items


PROC cell (CHAN BYTE in?, out!)
  WHILE TRUE
    BYTE largest:
    SEQ
      in ? largest
      WHILE largest <> end.marker
        BYTE next:
        SEQ
          in ? next
          IF                    -- output smaller, keep larger
            largest >= next
              out ! next
            TRUE                -- i.e. largest < next
              SEQ
                out ! largest
                largest := next
      out ! end.marker
:
```



Here is the *serial* logic (a loop within a loop).

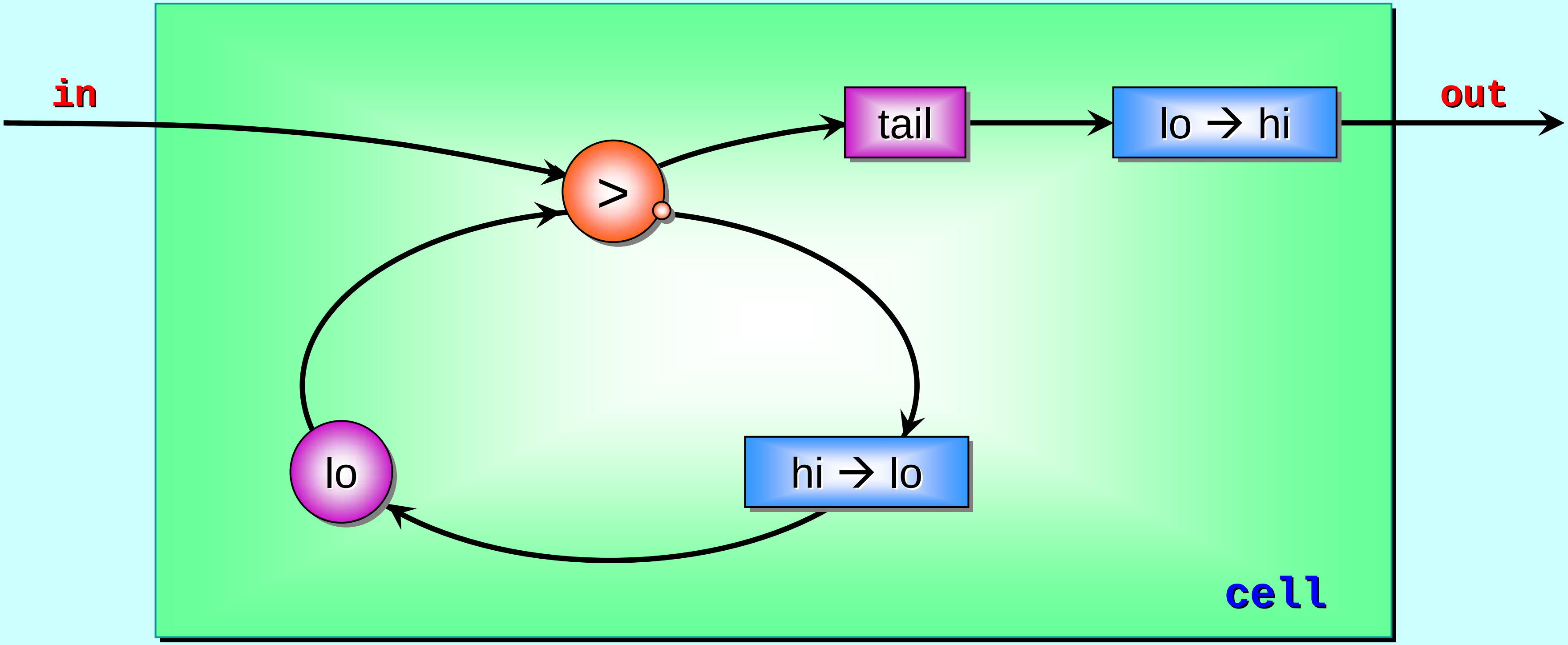
Let's simplify the logic within a **cell** process …



Here is the *parallel* logic …

Let's simplify the logic within a **cell** process …

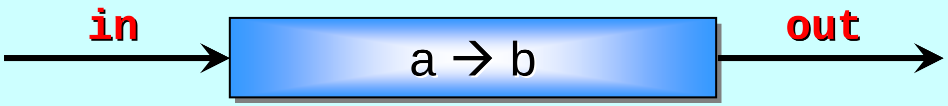
```
VAL BYTE hi IS 255:      -- assume > data items
VAL BYTE lo IS   0:      -- assume < data items
```



Here is the *parallel* logic …

The **largest** (so far) is trapped in the *feedback loop*.

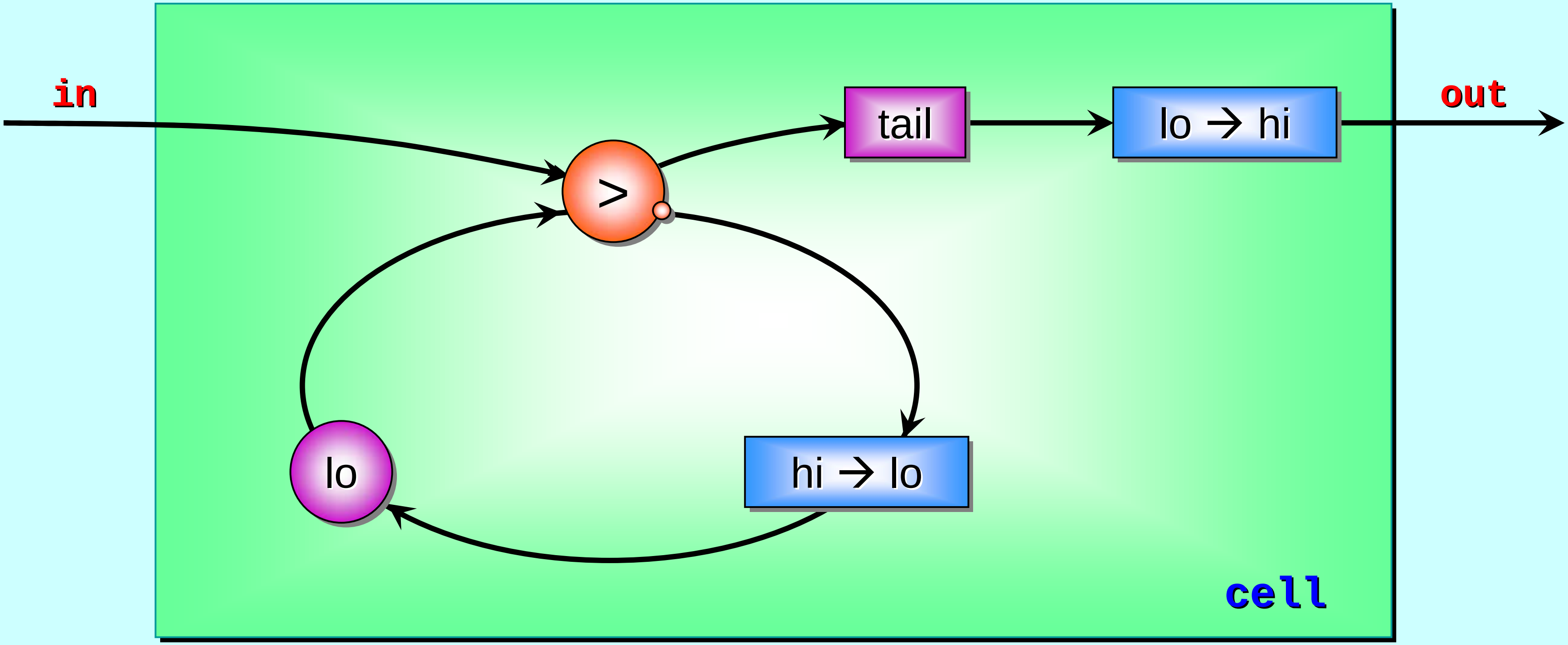
This process copies data through, substituting **a** for **b** …




```
PROC substitute (VAL BYTE a, b, CHAN BYTE in?, out!)
  WHILE TRUE
    BYTE x:
    SEQ
      in ? x
      IF
        x = a
          out ! b
        TRUE
          out ! x
:
```

And finally, let's simplify the logic within a **cell** process ...

```
VAL BYTE hi IS 255:      -- assume > data items
VAL BYTE lo IS   0:      -- assume < data items
```

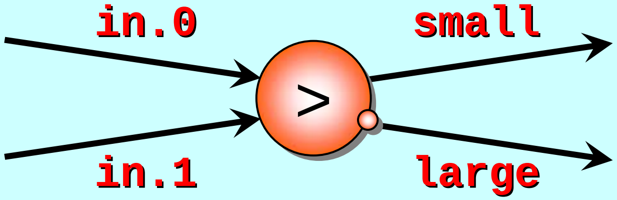


Here is the *parallel* logic ...

The **largest** (so far) is trapped in the *feedback loop*.

This is a primitive comparator …

```
PROC greater (CHAN BYTE in.0?, in.1?, small!, large!)
  WHILE TRUE
    BYTE x.0, x.1:
    SEQ
      PAR
        in.0 ? x.0
        in.1 ? x.1
      IF
        x.0 < x.1
          PAR
            small ! x.0
            large ! x.1
        TRUE
          PAR
            small ! x.1
            large ! x.0
:
```



Hence, the asymmetric design of its icon.

Note: **gt** is symmetric on its input channels, but not on its output channels!

Stateless Components

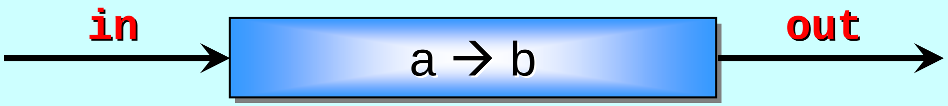
All the *primitive* process components in the *'Legoland'* catalogue (**`id`**, **`succ`**, **`plus`**, **`delta`**, **`prefix`**, **`tail`**, **…**) plus the ones just presented (**`substitute`**, **`greater`**) are *stateless*.

This means they are mathematical functions. They transform input values to output values without reference to past events: the same inputs yield the same outputs. *They have no memory – no state.*

Memory emerges when they are connected in circuits with feedback loops (**`numbers`**, **`integrate`**, **`cell`**, **…**).

Stateless components are trivial to reason about – we don't have to think about loops! They are also easy to cast into silicon – as, of course, are circuits built from them.

Stateless Components

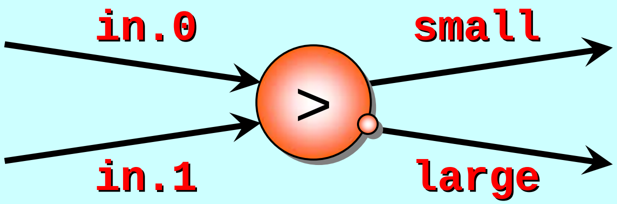



```
PROC substitute (VAL BYTE a, b, CHAN BYTE in?, out!)
  WHILE TRUE
    BYTE x:
    SEQ
      in ? x
      IF
        x = a
          out ! b
        TRUE
          out ! x
:
```

loop-free logic

Stateless Components

```
PROC greater (CHAN BYTE in.0?, in.1?, small!, large!)
  WHILE TRUE
    BYTE x.0, x.1:
    SEQ
      PAR
        in.0 ? x.0
        in.1 ? x.1
      IF
        x.0 < x.1
          PAR
            small ! x.0
            large ! x.1
        TRUE
          PAR
            small ! x.1
            large ! x.0
:
```



loop-free logic

Replicators (*components and test-rigs*)

Replicated **PAR** and **SEQ** ...

The **SORT PUMP** …

Component testing …

Stateless components …

The **SORT GRID** …

Replicated **IF** …

Replicator **STEP** sizes …

And Finally …

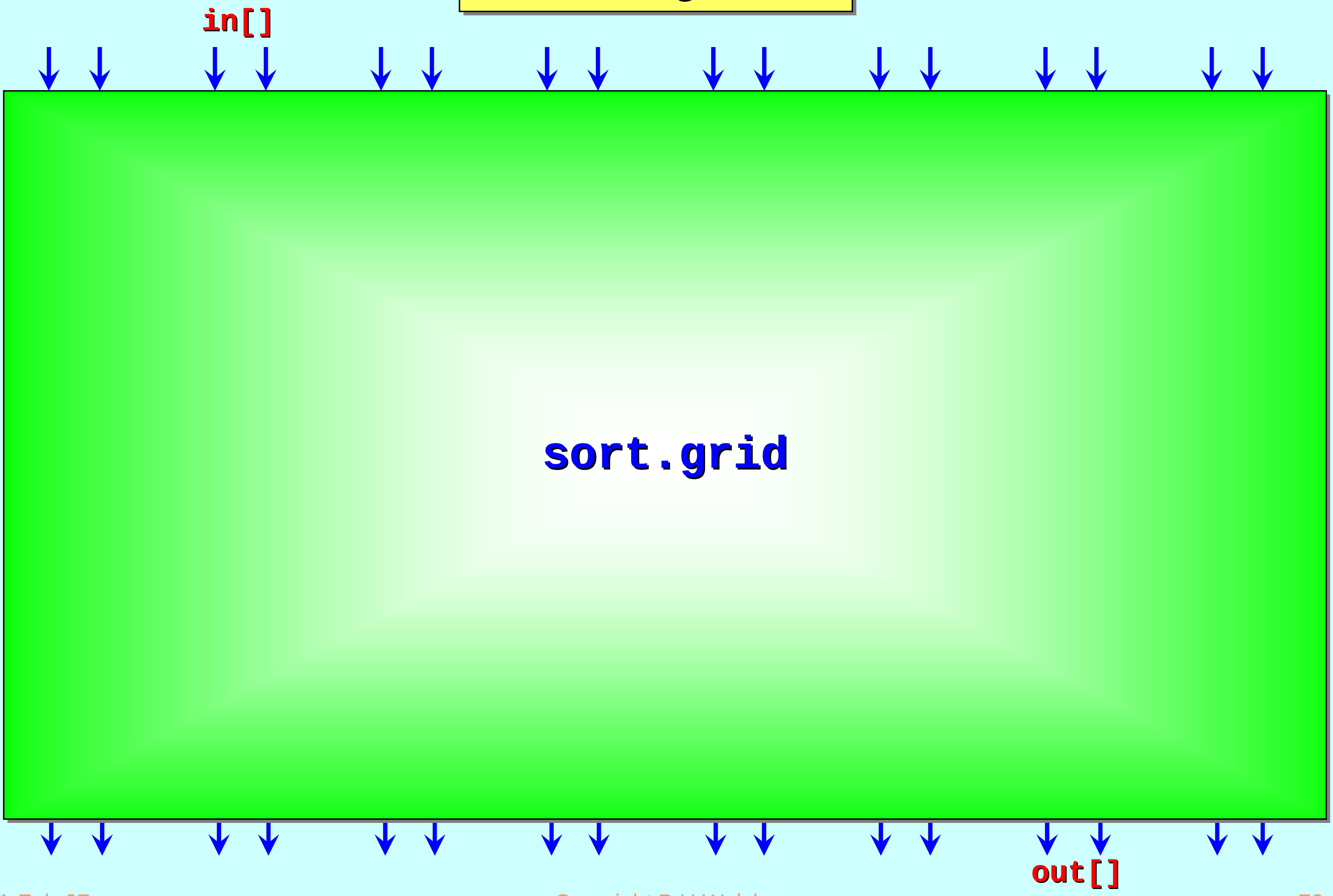
On a *serial* processor, *bubble-sort* takes $O(n^2)$ computation time, where n is the number of items being sorted. Cleverer algorithms (such as *quick-sort* or *shell-sort*) take $O(n*log(n))$.

With $O(n)$ processing elements, the *sort-pump* takes $O(n)$ computation time, with respect to each group of n items being sorted. If we only present data serially (i.e. one item at a time), supply takes $O(n)$ time … so *sort-pump* cannot be beaten! *But we do need a continuous supply of groups.*

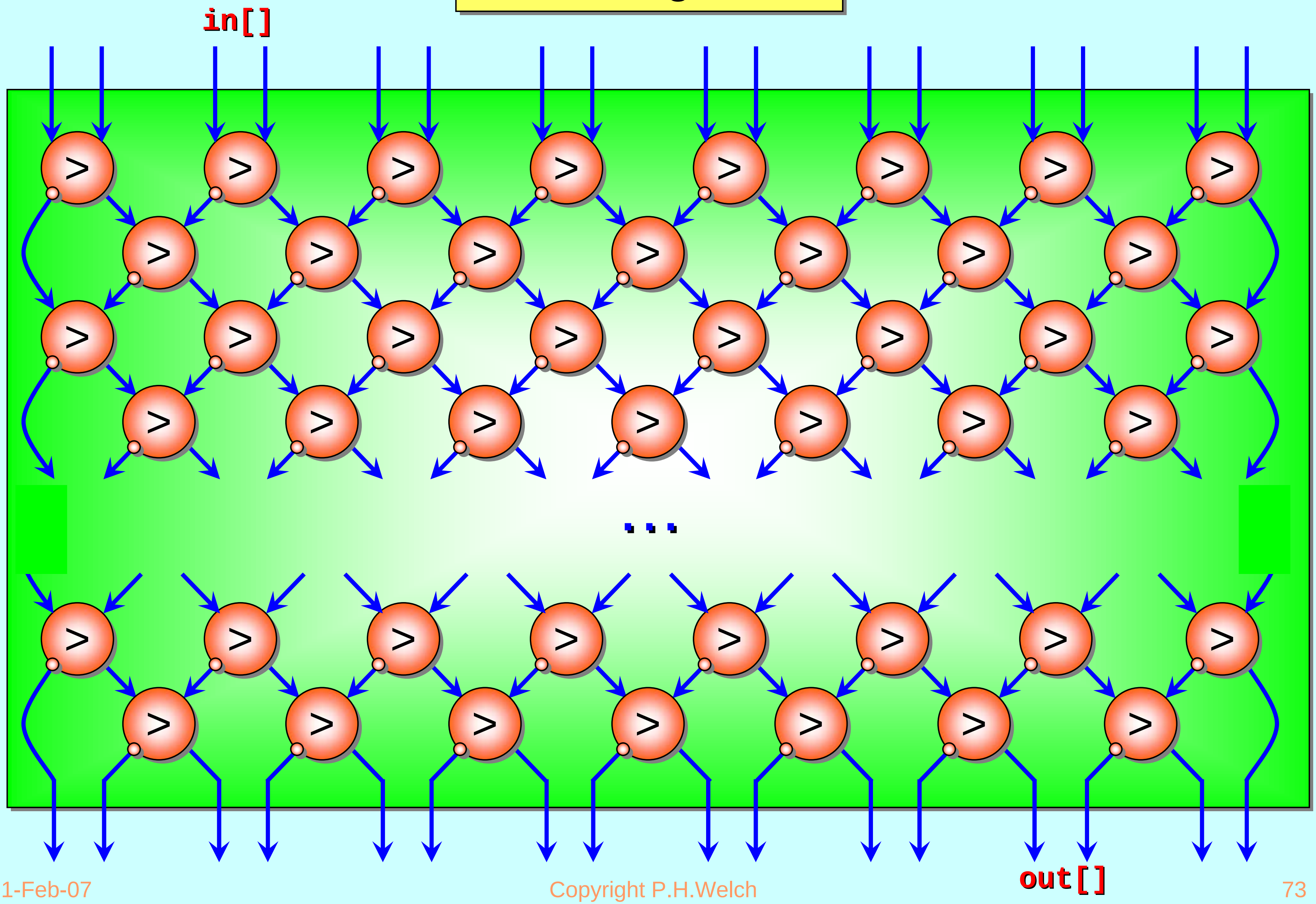
Question: with $O(n^2)$ processing elements, can we sort groups of n items in $O(1)$ time? Of course, we will have to present data in parallel (i.e. $O(1)$ time) and have a continuous supply.

Answer: Yes. *And it's easy!*

sort.grid



sort.grid



If the comparators are implemented on separate pieces of silicon *(i.e. we have a physically parallel engine)*, the speed at which data flows through is the *slowest* of:

- the speed at which data is offered;
- the cycle speed for each comparator;
- the inter-cell communication speed.

The speed is independent of the number of comparators – which means that it is independent of the number of items being sorted.

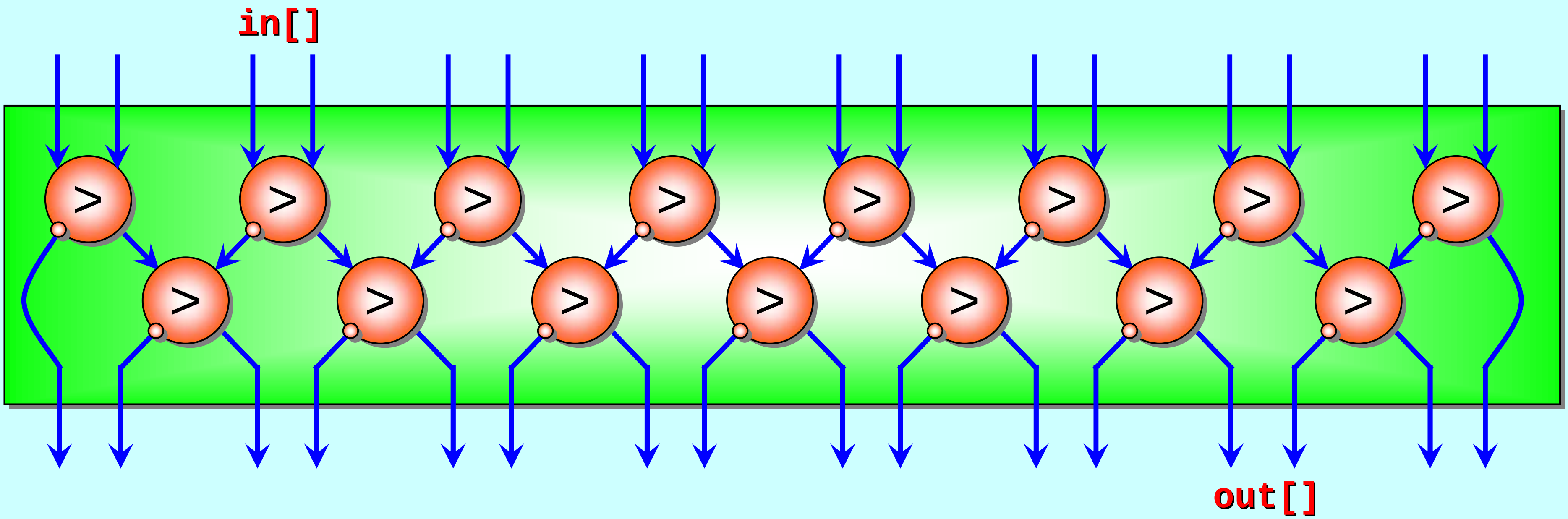
Each group of data *enters* and *exits* the grid *in parallel*. All comparators operate *in parallel*. After each *(unit time)* cycle, a sorted group emerges. We have an *O(1)* sorting engine:

`sort.grid`. ☺ ☺ ☺

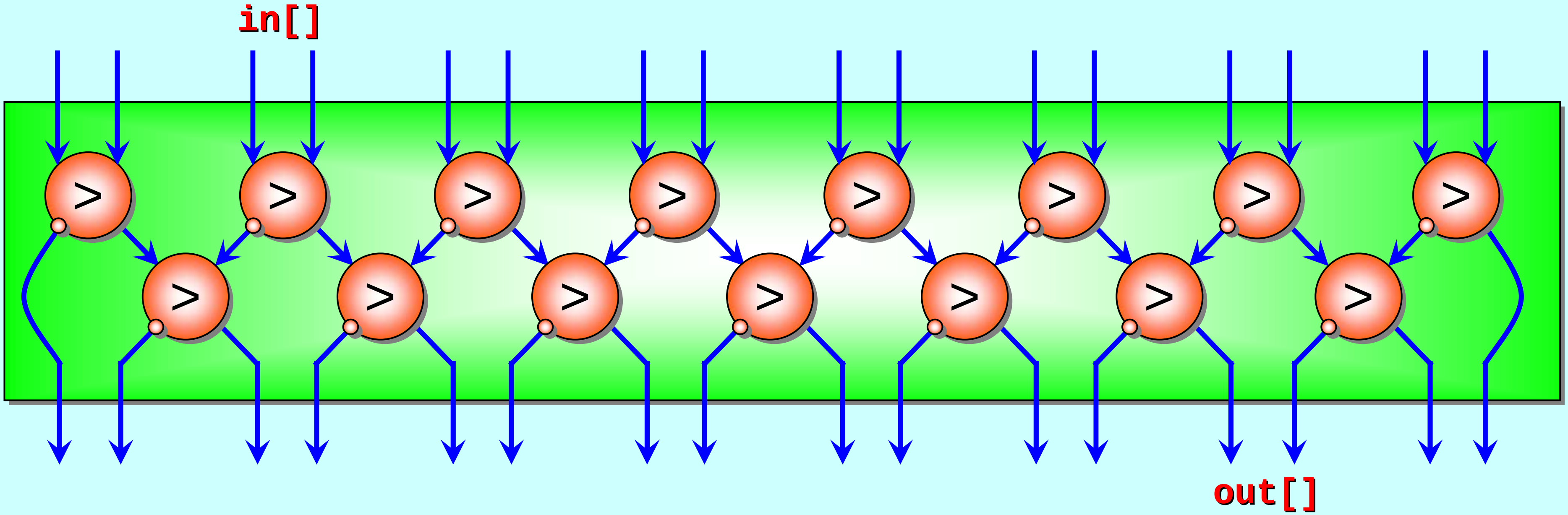
sort.grid

For groups up to size **16**, we need **16** rows of (`gt`) comparators. The *even* rows have **8** each and the *odd* rows have **7**.

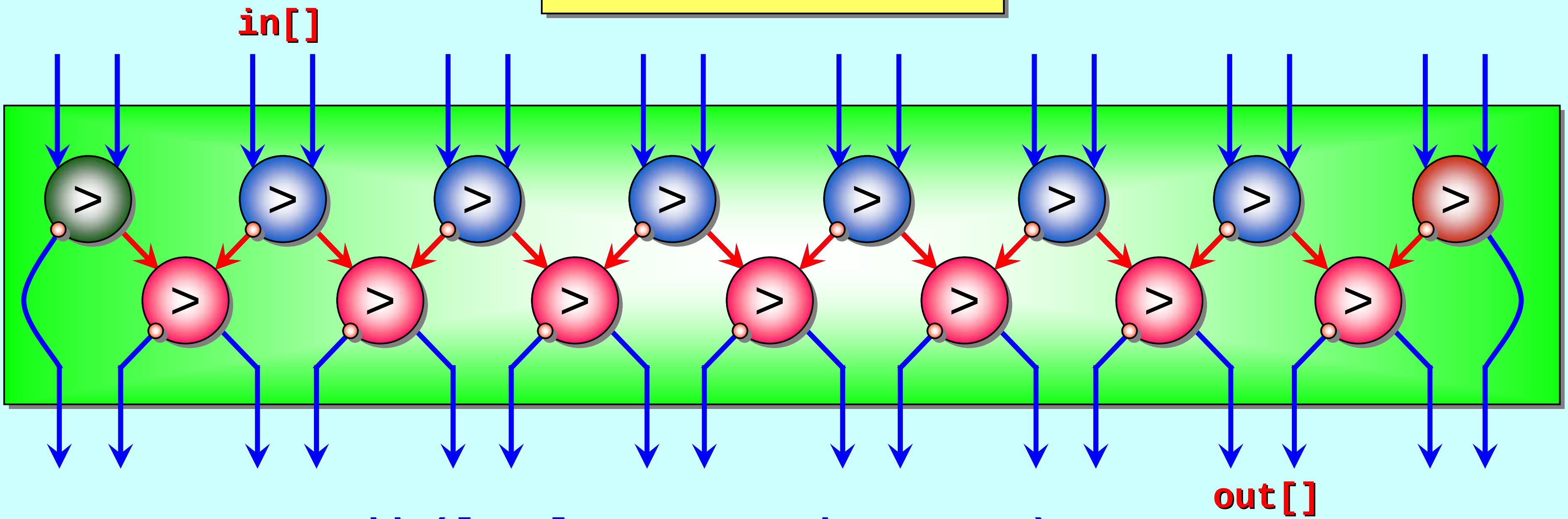
Coding: to keep things easy, let's first program an *even-odd* pair of rows …



even.odd



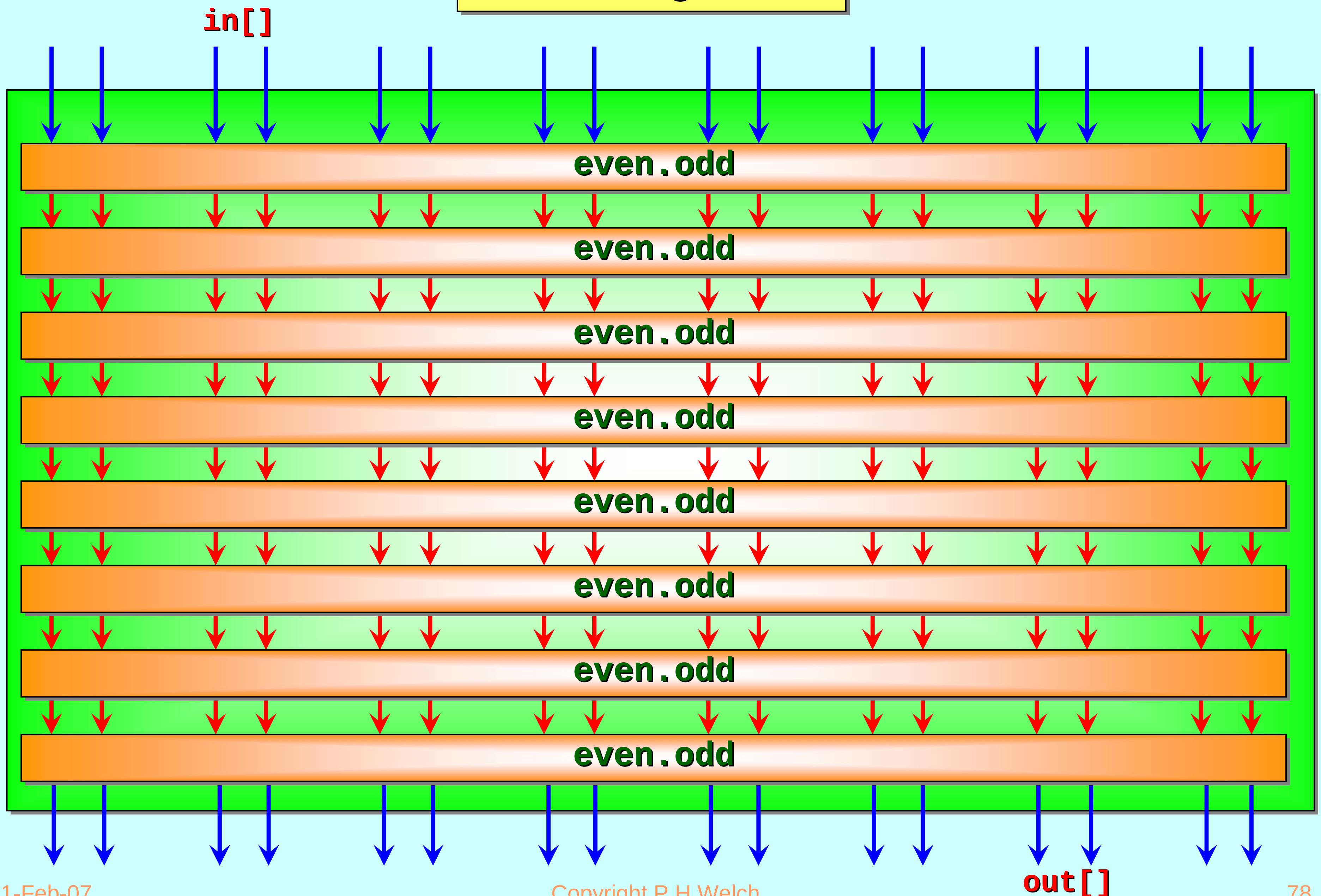
even.odd



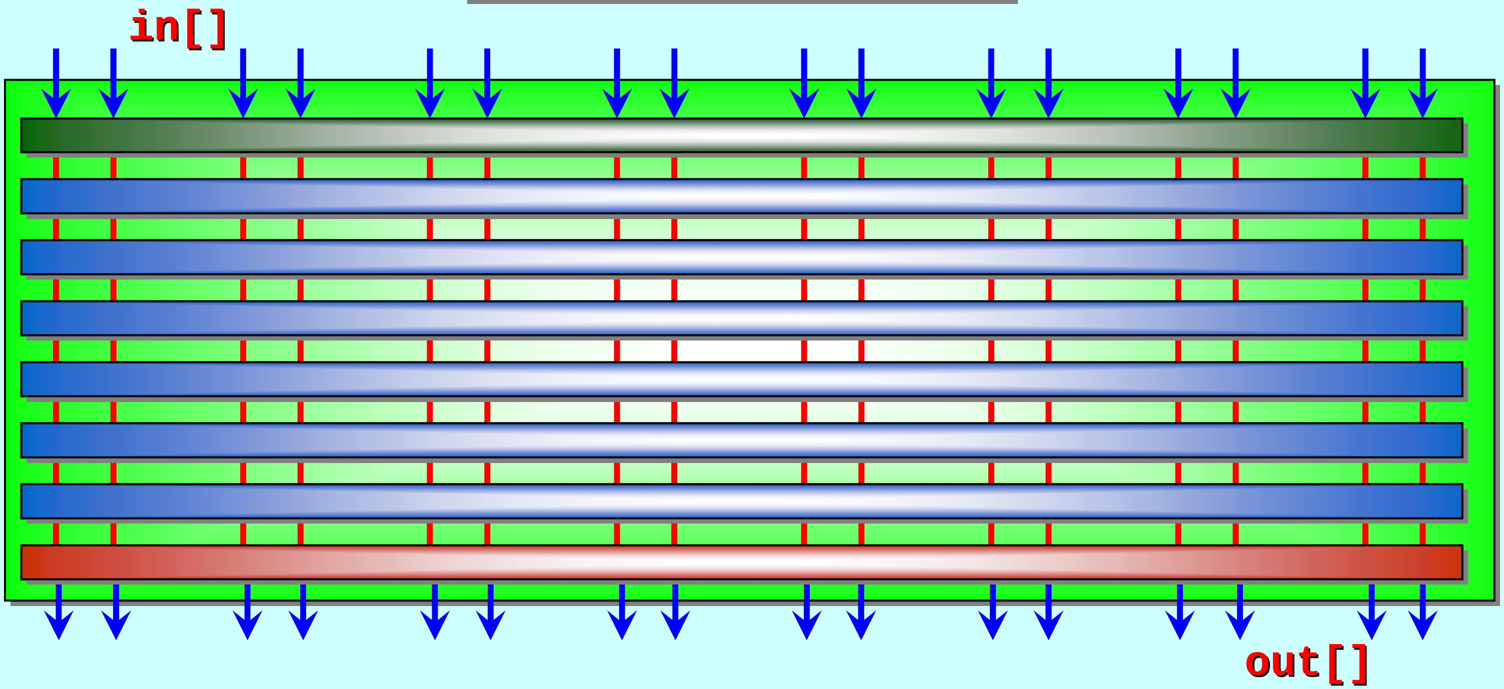

```
PROC even.odd ([max]CHAN BYTE in?, out!)
  [max-2]CHAN BYTE c:
  PAR
    gt (in[0]?, in[1]?, out[0]!, c[0]!)
    PAR i = 2 FOR (max/2) – 2 STEP 2
      gt (in[i]?, in[i+1]?, c[i-1]!, c[i]!)
    gt (in[max-2]?, in[max-1]?, c[max-3]!, out[max-1]!)
    PAR i = 1 FOR (max/2) – 1 STEP 2
      gt (c[i-1]?, c[i]?, out[i]!, out[i+1]!)
:
```

See replicator STEP sizes (later) …

sort.grid


in[]
even.odd
even.odd
even.odd
even.odd
even.odd
even.odd
even.odd
even.odd
out[]

sort.grid




```
PROC sort.grid ([max]CHAN BYTE in?, out!)
  [(max/2)-1][max]CHAN BYTE c:
  PAR
    even.odd (in?, c[0]!)
    PAR i = 0 FOR (max/2) – 2
      even.odd (c[i]?, c[i+1]!)
    even.odd (c[(max/2)–2]?, out!)
:
```

Exercise:

Build a test-rig for `sort.grid` …

☺ ☺ ☺ ☺ ☺ ☺

Replicators (*components and test-rigs*)

Replicated **PAR** and **SEQ** ...

The **SORT PUMP** …

Component testing …

Stateless components …

The **SORT GRID** …

Replicated **IF** …

Replicator **STEP** sizes …

Summary of Replicators (SEQ, PAR)

+

One New Replicator (IF)

The replicated SEQ is like a very clean for-loop.

INT declaration

first value

number of replications

```
SEQ i = start FOR count
  <process i>
```

In Java or C:

```
for (int i = start; i < (start + count); i++) {
  <code i>
}
```

Must not change the value of i, start or count

The replicated PAR has no correspondence in Java or C.

INT declaration

first value

number of replications

```
PAR i = start FOR count
  <process i>
```

In Java or C:

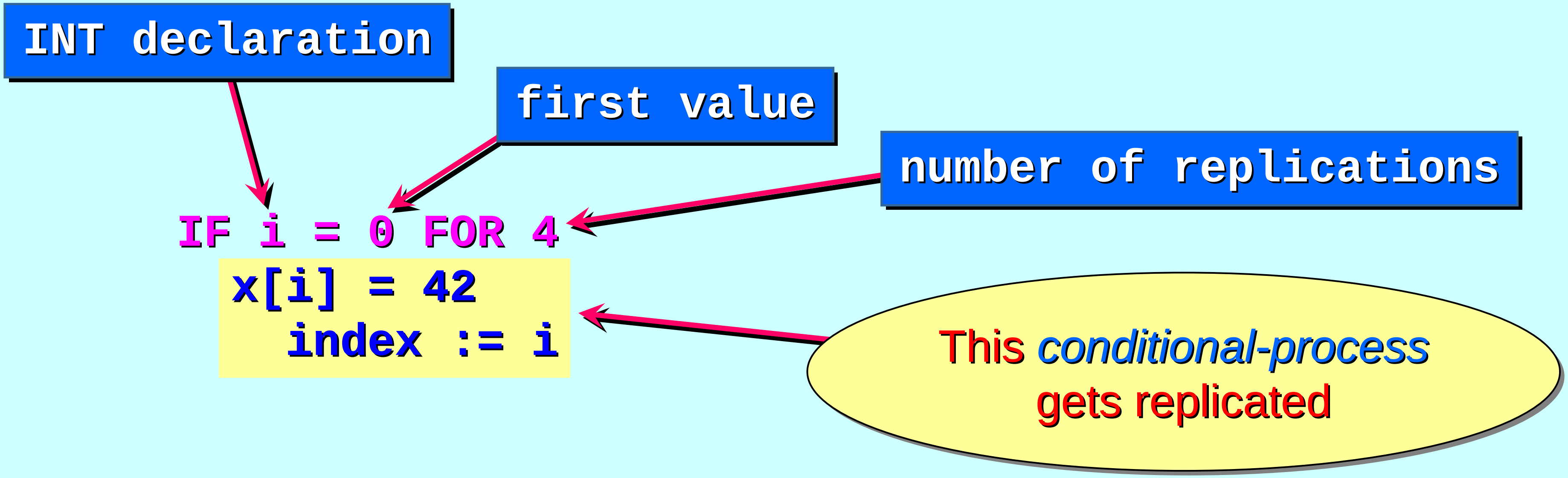
... silence

Replicated IFs

So far, we have seen the **occam-π** process constructors **SEQ**, **PAR**, **IF** and **WHILE**. (Still to come are **ALT** and **CASE**.)

We have seen how **SEQ** and **PAR** can be *replicated*. So, also, can the **IF** and (later) the **ALT**. Here is a *replicated* **IF**:

```
IF i = 0 FOR 4
  x[i] = 42
    index := i
```



Replicated **IF**s

So far, we have seen the ***occam-π*** process constructors **SEQ**, **PAR**, **IF** and **WHILE**. (Still to come are **ALT** and **CASE**.)

We have seen how **SEQ** and **PAR** can be *replicated*. So, also, can the **IF** and (later) the **ALT**. Here is a *replicated* **IF**:

```
IF i = 0 FOR 4
  x[i] = 42
    index := i
```

≡

```
IF
  x[0] = 42
    index := 0
  x[1] = 42
    index := 1
  x[2] = 42
    index := 2
  x[3] = 42
    index := 3
```

Replicated **IF**s

This code searches the first **4** elements of the array **x** for the value **42**. The search is *sequential*, starting from element **0** and proceeding upwards. If successful, the variable **index** is set to the (first) index of the **x** array element equal to the target. If unsuccessful, this code will crash!

```
IF i = 0 FOR 4
  x[i] = 42
    index := i
```

≡

```
IF
  x[0] = 42
    index := 0
  x[1] = 42
    index := 1
  x[2] = 42
    index := 2
  x[3] = 42
    index := 3
```

To avoid that crash, we need a final condition that catches the flow of control should all the other conditions fail:

```
IF
  x[0] = 42
    index := 0
  x[1] = 42
    index := 1
  x[2] = 42
    index := 2
  x[3] = 42
    index := 3
  TRUE
    index := -1
```

To express this using an **IF**-replicator (which we need if we were searching the through n elements, where n is known only at run-time), we need a *nested* **IF** ...

where **index** is set to **-1**, an *illegal array index*, used here to indicate that the *search failed*.

Nested **IF**s

```
IF
  <condition 0>
    <process 0>
  IF
    <condition 1>
      <process 1>
    <condition 2>
      <process 2>
  <condition 3>
    <process 3>
```

≡

```
IF
  <condition 0>
    <process 0>
  <condition 1>
    <process 1>
  <condition 2>
    <process 2>
  <condition 3>
    <process 3>
```

The inner **IF** disappears and its *conditional processes* align with the *conditional processes* of the outer **IF**.

Nested IFs

```
IF
  <condition 0>
    <process 0>
  IF i = 0 FOR n
    <rep condition i>
      <rep process i>
  <condition 1>
    <process 1>
```

≡

```
IF
  <condition 0>
    <process 0>
  IF
    <rep condition 0>
      <rep process 0>
    .
    .
    .
    <rep condition (n-1)>
      <rep process (n-1)>
  <condition 1>
    <process 1>
```

Nested **IF**s are mainly useful … *when the inner or outer is replicated.*

Nested **IF**s

```
IF
  <condition 0>
      <process 0>
  IF i = 0 FOR n
    <rep condition i>
        <rep process i>
  <condition 1>
        <process 1>
```

≡

```
IF
  <condition 0>
      <process 0>
  <rep condition 0>
      <rep process 0>
  .
  .
  .
  <rep condition (n-1)>
      <rep process (n-1)>
  <condition 1>
      <process 1>
```

They enable us to **IF** between *sequenced* and *individual* conditions.

Replicated IFs

```
IF
  x[0] = 42
    index := 0
  x[1] = 42
    index := 1
  x[2] = 42
    index := 2
  x[3] = 42
    index := 3
  TRUE
    index := -1
```

≡

```
IF
  IF i = 0 FOR 4
    x[i] = 42
      index := i
  TRUE
    index := -1
```

where **`index`** is set to **`-1`**, an *illegal array index*, used here to indicate that the *search failed*.

Bounded Linear Search (occam-π)

The *'bounded linear search'* is the only common use for a *replicated* **IF** – but it is a good one!

Problem: find the index of the first element of some array, **x**, that matches **some.condition()**:

```
IF
  IF i = 0 FOR SIZE x
    some.condition (x[i])
      ...  we found it at index i
  TRUE
    ...  we didn't find it
```

first value

number of replications

Note: the above code searches (potentially) the whole array.

We can restrict the search by setting *first* and *replicate* values (of the *replicated* **IF**) appropriately.

Bounded Linear Search (*Java / C*)

Problem: find the index of the first element of some array, **x**, that matches **some.condition()**:

```
{ int i = 0;
  bool found = false;
  for (i = 0; i < x.length; i++) {
    if (someCondition (x[i])) {
      found = true;
      break;
    }
  }
  if (found) {
    ...  we found it at index i
  } else {
    ...  we didn't find it
  }
}
```

Bounded Linear Search (Java / C)

Problem: find the index of the first element of some array, **x**, that matches **some.condition()**:

Actually, this can be expressed in almost a compact form as in **occam-π** ... but we need to resort to a *labelled block* with *non-local break-out*:

```
BLS: {
  for (int i = 0; i < x.length; i++) {
    if (someCondition (x[i])) {
      ...  we found it at index i
      break BLS;
    }
  }
  ...  we didn't find it
}
```

Replicators (*components and test-rigs*)

Replicated **PAR** and **SEQ** ...

The **SORT PUMP** …

Component testing …

Stateless components …

The **SORT GRID** …

Replicated **IF** …

Replicator **STEP** sizes …

Replicator STEP Sizes

Normally, the replicator control value increments by **1** for each replicated instance.

However, we may define an arbitrary **STEP** size for this increment:

INT declaration

first value

number of replications

increment

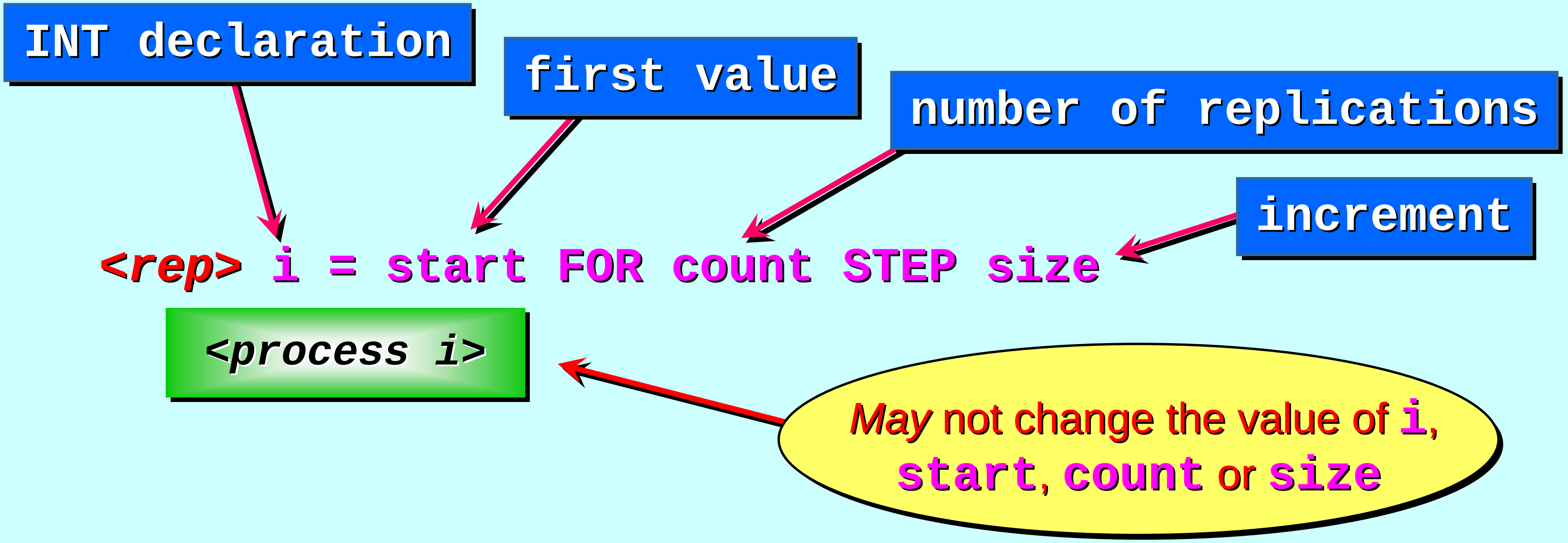
```
<rep> i = start FOR count STEP size
  <process i>
```

May not change the value of **i**, **start**, **count** or **size**

Replicator STEP Sizes

The ***<rep>*** constructor is one from: **SEQ**, **PAR**, **IF** and *(later)* **ALT**.

The **start**, **count** and **size** may be any **INT** expressions. The values of **i** and *any variables* in **start**, **count** and **size** cannot be changed by the replicated process.



Summary: a replicated SEQ is a very clean for-loop.

INT declaration — first value — number of replications — increment

```
SEQ i = start FOR count STEP size
  <process i>
```

In Java or C:

```
{ int i = start;
  for (int ii = 0; ii < count; ii++) {
    <code i>
    i += size;
  }
}
```

Must not use **ii**

Must not change the value of **i**, **start**, **count** or **size**

The replicated PAR has no correspondence in Java or C.

INT declaration

first value

number of replications

increment

```
PAR i = start FOR count STEP size
  <process i>
```

In Java or C:

… silence

The replicated IF gives a *'Bounded Linear Search'*

INT declaration

first value

number of replications

increment

```
IF
  IF i = start FOR count STEP size
    <condition i>
      <found-process i>
  TRUE
    <not-found-process>
```

this is what gets replicated

Unless we know that the search will succeed, we must nest the *replicated* IF inside a plain IF to catch any failure.

‘Stepping and Bounded Linear Search’ (Java / C)

```
BLS: {
  int i = start;
  for (int ii = 0; ii < count; ii++) {
    if ( <condition i> ) {
      <found-code i>
      break BLS;
    }
    i += size;
  }
  <not-found-code>
}
```

The **<condition i>** expression and **<found-code i>** code *must not* use **ii** and *must not* change the value of **i**, **start**, **count** or **size**.