BG-simulation and Renaming

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    - Simulation Algorithm
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    - Computability Consequences
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    - Problem Statement
    - Renaming and Crashes
    - A Splitter-based Algorithm
    - A Snapshot-based Algorithm

1 BG-Simulation
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BG-Simulation

The BG-Simulation algorithm allows to wait-free simulate a t-resilient system of n asynchronous processes sharing memory with $t+1$ asynchronous simulators sharing memory.

- $t + 1$ asynchronous simulators $\pi_0, \ldots, \pi_t$;

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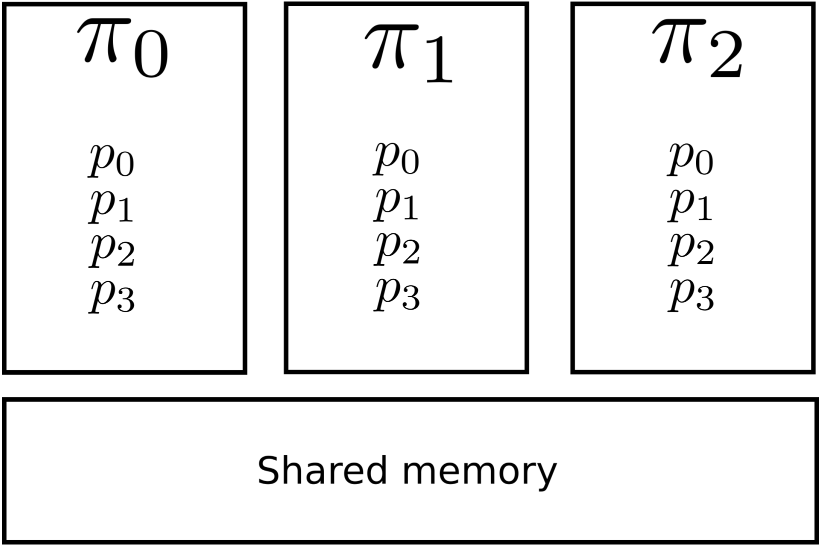
We must ensure that, in any simulated execution, at most t simulated processes crash.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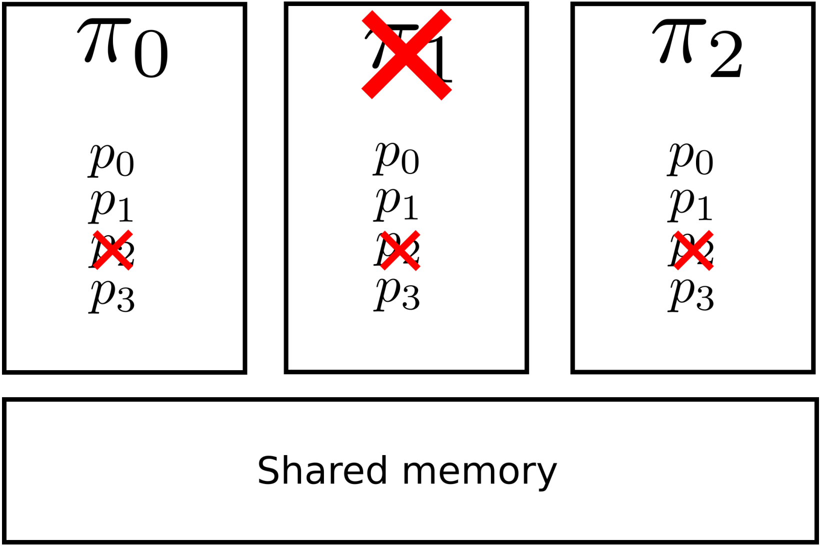
Shared memory



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Shared memory

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- each simulator π_s simulates all the processes $p_0, \ldots, p_{n-1}$;
- it computes an output $output_i$ for each process that do not crash during the simulation.

We consider deterministic programs $prog_i$ supposed to be of the following form:

$state_i \leftarrow init_i$
while not_decided($state_i$) **do**
  $val \leftarrow$ next_write($state_i$)
  write(val, $\mathrm{MEM}[i]$)
  $snap_i \leftarrow$ snapshot(MEM)
  $state_i \leftarrow$ update_state($snap_i$, $state_i$)
end while
return compute_output($state_i$)

For each process p_i, simulator π_s maintains:

- p_i's state: *state*[*i*]

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- p_i's state: $state[i]$
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- a sequence number for p_i's last snapshot: $snap\_sn[i]$.

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- The crash of the simulator prevents future progress of any thread.
- Threads do not crash individually.

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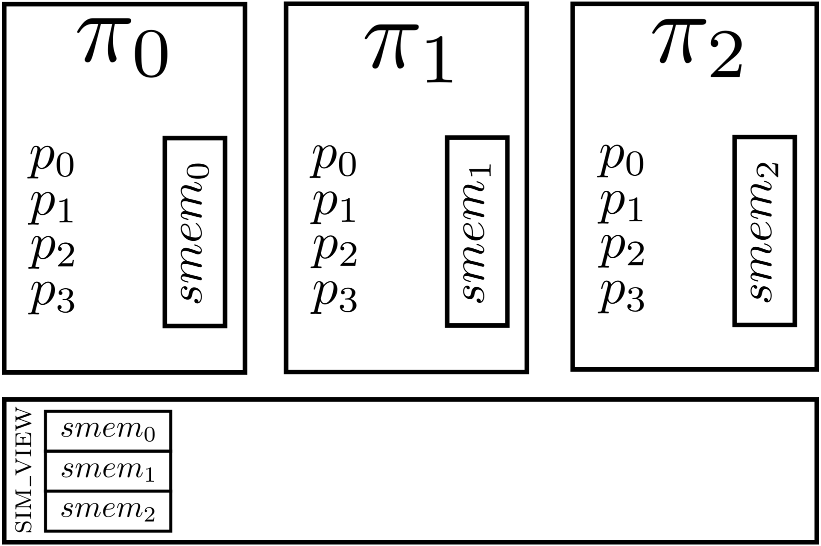
- π_s writes it's view $smem_s$ of the simulated shared memory in its assigned shared register $\text{SIM\_VIEW}[s]$;
- it can take an atomic snapshot of the views of other simulators $\text{SIM\_VIEW}[0, \ldots, t]$ on the simulated shared memory.
- $\text{SIM\_VIEW}[s'][i]$ is a pair containing the last value written by p_i according to simulator $\pi_{s'}$, and the corresponding sequence number.



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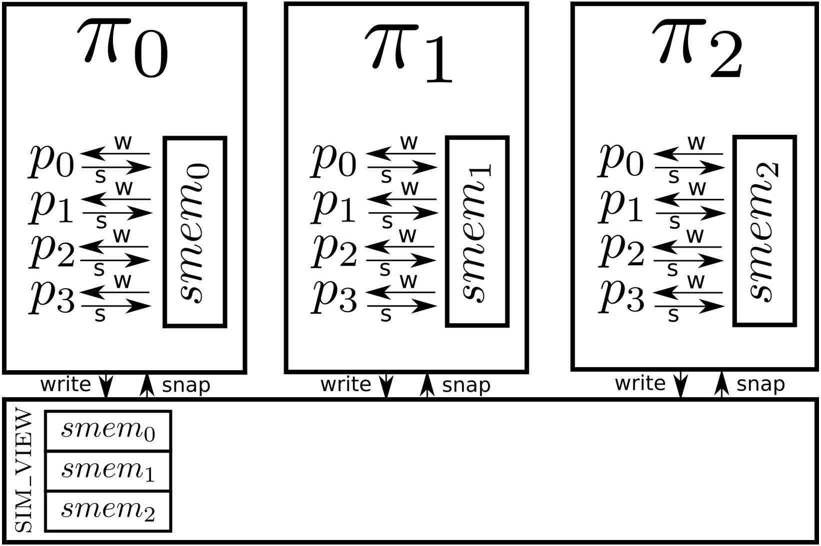
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SIM_VIEW

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We need to ensure the atomicity of the simulated shared memory.

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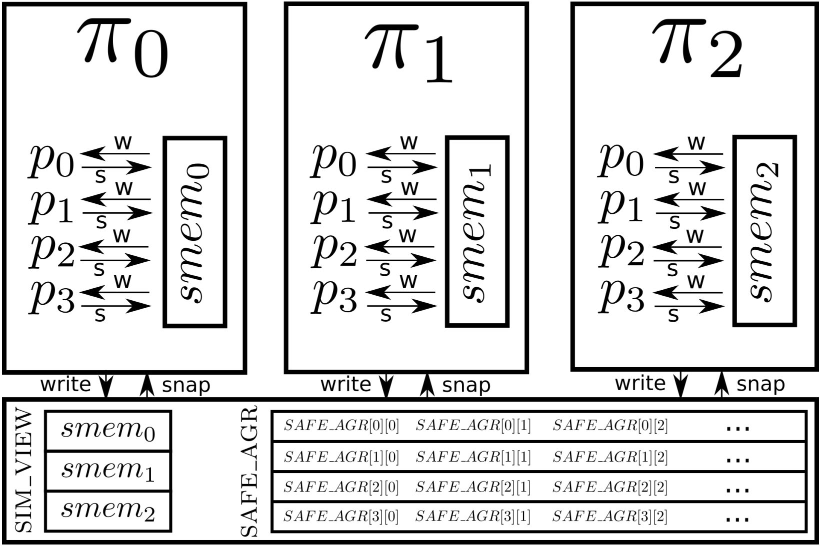
: At most one value is decided.

Validity
: A decided value is a proposed value.

In a crash-free system, safe-agreement objects implement consensus.

init $REG[0, \ldots, n-1] \leftarrow [\langle \bot, 0 \rangle]$
operation PROPOSE(v)
    $REG[s] \leftarrow \langle v, 1 \rangle$
    $snap_s \leftarrow REG.snapshot()$
    if $\exists x \ : \ snap_s[x].level = 2$ **then**
        $REG[s] \leftarrow \langle v, 0 \rangle$
    else
        $REG[s] \leftarrow \langle v, 2 \rangle$
    end if
end operation
operation DECIDE( )
    repeat
        $snap_s \leftarrow REG.snapshot()$
    until $\forall x \ : \ snap_s[x].level \neq 1$
    $x \leftarrow \min \{ y \mid snap_s[y] = 2 \}$
    return $snap_s[x].value$
end operation



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    $state_i \leftarrow$ update_state($snap_i$, $state_i$)
end while
return compute_output($state_i$)

$state_i \leftarrow init_i$; $write\_sn[i] \leftarrow 0$; $snap\_sn[i] \leftarrow 0$
while not_decided($state_i$) **do**
    $val \leftarrow$ next_write($state_i$)
    simulate_write($i, val, \mathrm{MEM}[i]$)
    $snap_i \leftarrow$ simulate_snapshot(i, MEM)
    $state_i \leftarrow$ update_state($snap_i, state_i$)
end while
return compute_output($state_i$)

operation $\text{SIMULATE\_WRITE}(i, val, \text{MEM}[i])$

$write\_sn[i] \leftarrow write\_sn[i] + 1$

$smem_s[i] \leftarrow \langle val, write\_sn[i] \rangle$

$\text{SIM\_VIEW}[s] \leftarrow smem_s$

end operation

operation SIMULATE_SNAPSHOT(i,MEM)
    $snap \leftarrow$ SIM_VIEW.$snapshot()$
    for $x \in \{1, \ldots, n\}$ **do**
        let z **be s.t.** $\forall y, snap[z][x].sn \geq snap[y][x].sn$
        $sim\_snap[x] \leftarrow snap[z][x]$
    end for
    $snap\_sn[i] \leftarrow snap\_sn[i] + 1$
    SAFE_AGR[i][$snap\_sn[i]$].PROPOSE(sim_snap)
    return SAFE_AGR[i][$snap\_sn[i]$].DECIDE()
end operation

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- $prog_i$ being deterministic, they also agree on the remaining of their simulations (including writes).
- A simulated write is linearized at the first moment a simulator π_s writes a $smem_s$ containing this write into SIM_VIEW[s].
- A simulated snapshot is linearized at the moment the simulator that proposes it to the safe-agreement took its corresponding snapshot of SIM_VIEW.

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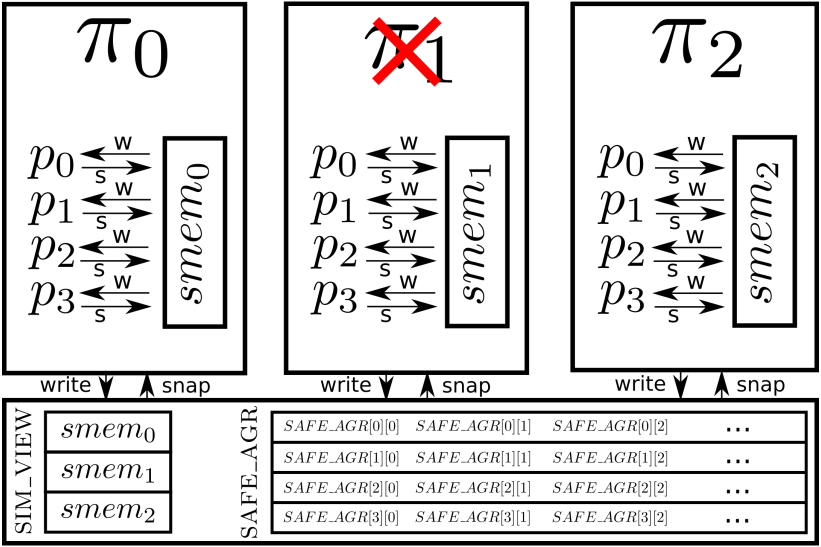
- If it crashes at that point, DECIDE operations of these objects may block forever for all simulators;
- the corresponding simulated processes then stop making progress.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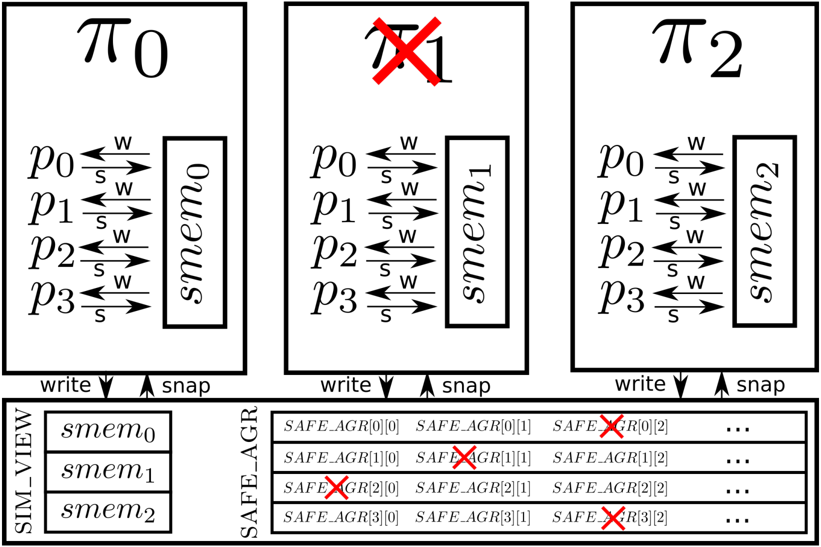
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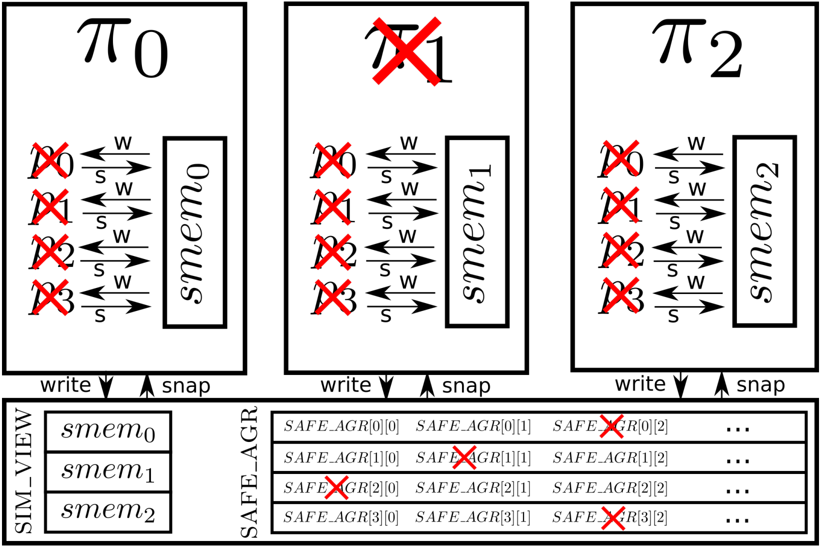

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We can easily force a thread never to be in more than one PROPOSE operation.

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    $snap \leftarrow$ SIM_VIEW.$snapshot()$
    for $x \in \{1, \ldots, n\}$ **do**
        let z **be s.t.** $\forall y, snap[z][x].sn \geq snap[y][x].sn$
        $sim\_snap[x] \leftarrow snap[z][x]$
    end for
    $snap\_sn[i] \leftarrow snap\_sn[i] + 1$
    enter mutex
    SAFE_AGR[i][$snap\_sn[i]$].PROPOSE(sim_snap)
    leave mutex
    return SAFE_AGR[i][$snap\_sn[i]$].DECIDE()
end operation

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The crash of a simulator can prevent the progress of at most one simulated process.

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BG-Simulation

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- They can simulate the execution of a protocol between $n > t$ asynchronous processes sharing a memory with at most t crashes.
- They need to be provided with:
  - a deterministic program for each simulated process;
  - an input for each simulated process.
- The correct simulators can then compute an output for each simulated process that do not block in the simulation.

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- $\mathcal{O}$ is the set of possible output configurations.
- $O \in \mathcal{O}$ is a vector of outputs, one for each process, possibly with some missing values (due to crashes).
- $\delta : \mathcal{I} \rightarrow 2^{\mathcal{O}}$ is a function that, to any input configuration $I \in \mathcal{I}$, associates the set $\delta(I) \subseteq \mathcal{O}$ of the output configurations that are allowed when starting from I.

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- Consensus, k-set agreement are decision tasks, renaming isn't.

Any decision task that we can solve with n processes and t crashes, we can solve it with $t+1$ processes and t crashes.

The study of decision tasks computability can be reduced to the $n-1$-resilient case.

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Example

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  - Use n safe-agreements to decide on how to map simulators inputs on processes.
  - Simulate the protocol.
  - Decide any value decided in the simulation.
- This solves t-set agreement between our $t + 1$ simulators.
- Contradiction, so there is no such algorithm.

What matters is the number of crashes, not the number of processes.

- Borowsky, E., Gafni, E., Lynch, N., Rajsbaum, S.: *The BG distributed simulation algorithm*. Distributed Computing 14(3), 127146 (2001).

References

- Borowsky, E., Gafni, E., Lynch, N., Rajsbaum, S.: *The BG distributed simulation algorithm*. Distributed Computing 14(3), 127146 (2001).
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- up to $n-1$ of them may crash;
- they are given names in a large namespace $\{-N, \ldots, N\}, N >> n$;
- k-renaming provides them with a GET_NAME operation that returns a new unique name in a smaller namespace $\{1, \ldots, k\}$.

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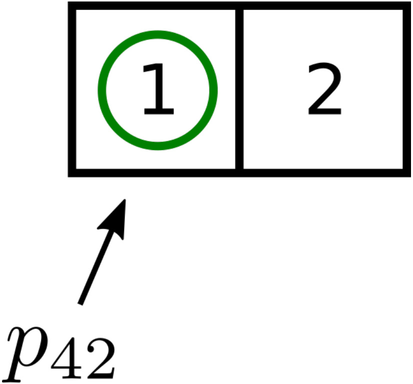
- The "big" names are just a way to break symmetry, renaming protocols allow to dynamically compute unique identifiers.
- Several problems can be reduced to renaming (e.g. picking a unique transmitting frequency).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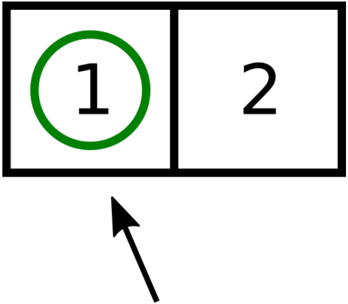
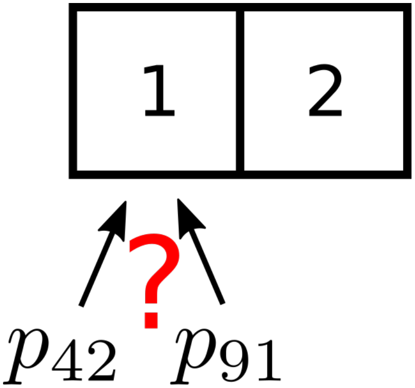
p_{42}



p_{91}


1
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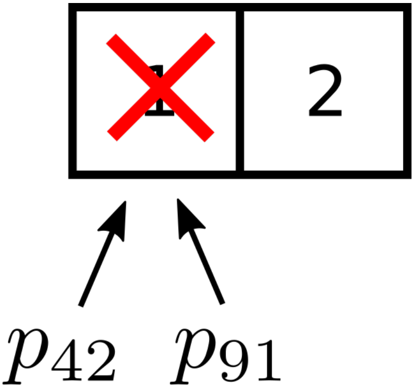
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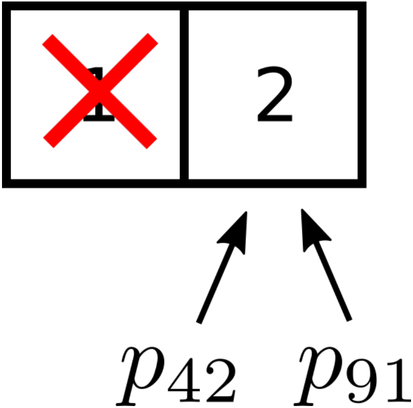
1
2
p_{42}
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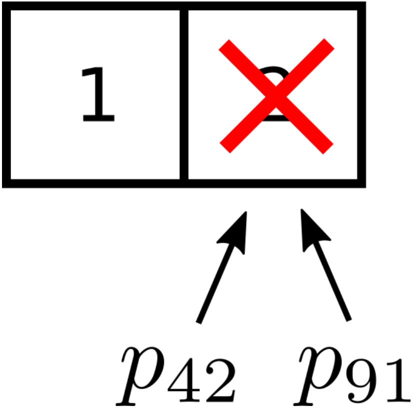
1
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p_{42}
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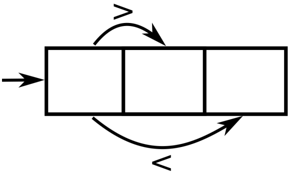

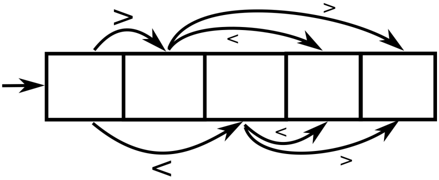

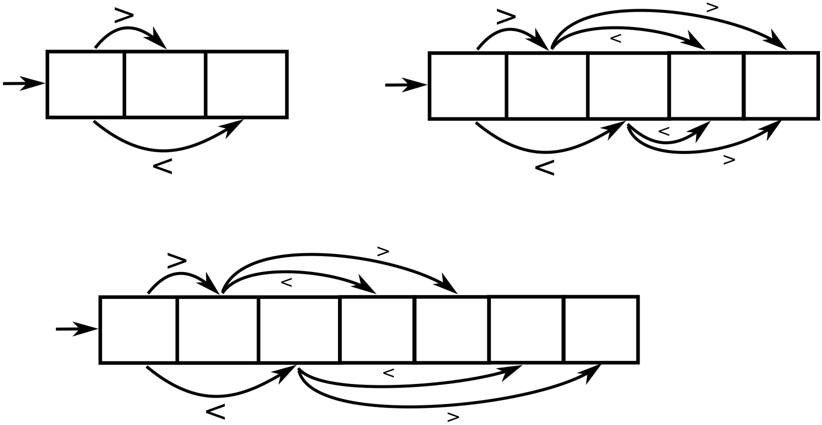

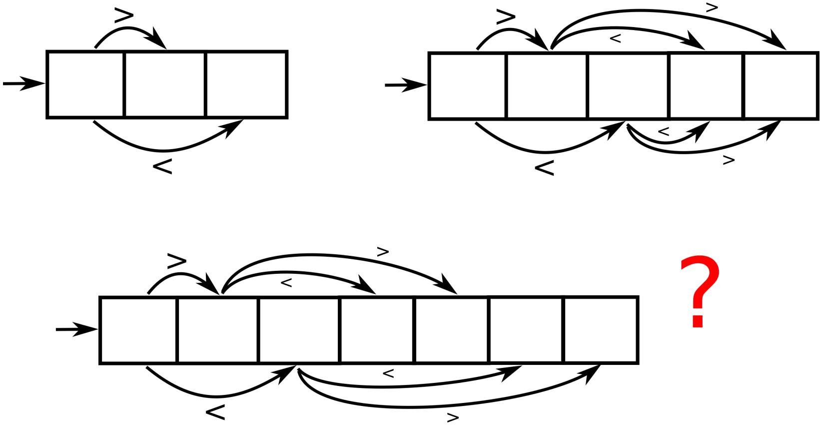

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Adaptive Renaming

Ideally the protocol should be adaptive: the largest name obtained should depend on the actual number of participating processes, not on the total number of processes.

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- If x processes invoke DIRECTION:
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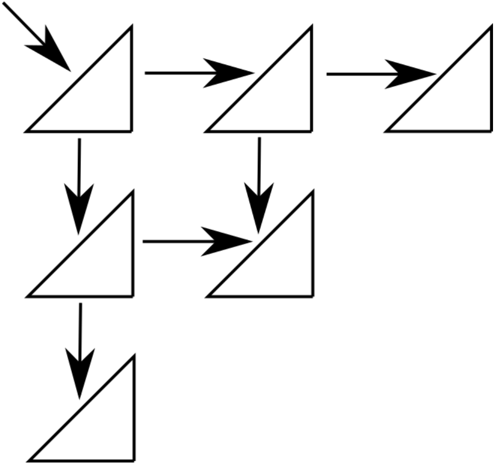
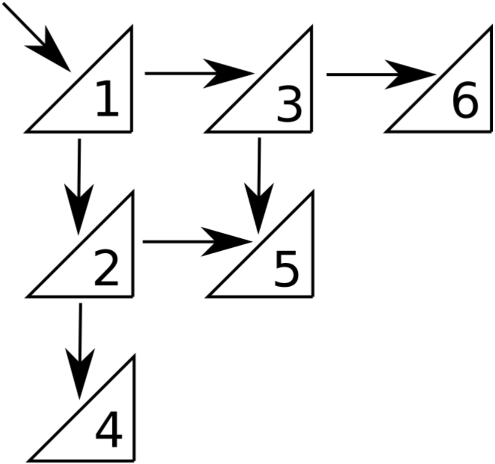
  - at most $x - 1$ obtain *down*;
  - at most one obtains *stop*.
- Any invocation to DIRECTION by a correct process terminates.



```
operation NEW_NAME(id)
    d ← 1; r ← 1; move ← down
    while move ≠ stop do move ← S[d, r].DIRECTION(id);
        if move = right then
            r ← r + 1
        else if move = down then
            d ← d + 1
        end if
    end while
    return (d + r − 1)(d + r − 2)/2 + r
end operation
```


1
3
6
2
5
4

Great! But we can do even better.

```
operation NEW_NAME(id)
    name ← 1
    while true do
        MEM[i] ← ⟨id, name⟩
        snap ← MEM.snapshot()
        if ∀j ≠ i : snap[j].name ≠ name then
            return name
        else
            free ← names of {1, . . . , ∞} that do not appear in snap
            rank ← rank of id in the set of identifiers appearing in snap
            name ← name at position rank in free
        end if
    end while
end operation
```

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Termination If a set of processes never decides, their *rank* variables will stabilize on distinct values.

The one with the smallest *rank* is then eventually alone to propose its new name. Contradiction.

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- Renaming algorithms distribute new unique names from a smaller namespace.