Immediate Snapshot

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Snapshot

A **snapshot** has two operations: ***update()*** and ***scan()*** and maintains an array x of size n

Sequential specification

scan():

- Return (x)

update(i, v):

- x[i] := v;
- Return (OK)

Motivation for immediate snapshot

Snapshot

- Update some state
- Take a “picture” of all states
- Separately

Immediate snapshot

- Immediately take a “picture” of all states after updating a state

Semantics

The memory is accessed via a single **update_snapshot** operation

Semantics: each write operation, in addition to writing, also returns an atomic snapshot

“Weakly atomic” = runs of standard atomic snapshot include runs of immediate snapshot

The power of registers

Can immediate snapshot be implemented by atomic registers?

- Yes. At least for one-shot version

One-shot: Each process invokes at most once that operation

Immediate snapshot

An **immediate snapshot** has a single operation: ***update_snapshot()*** and maintains an array x of size n

Sequential specification

update_snapshot(vi):

- x[i] := vi;
- Return {(1, x[1]), (2, x[2]), …, (n, x[n])}

Properties

Liveness. An invocation of **update_snapshot()** terminates

Self-inclusion. $(i, v_i) \in view_i$

Containment. $view_i \subseteq view_j$ or $view_j \subseteq view_i$

Immediacy. If $(j, v_j) \in view_i$, then $view_j \subseteq view_i$

Naive implementation

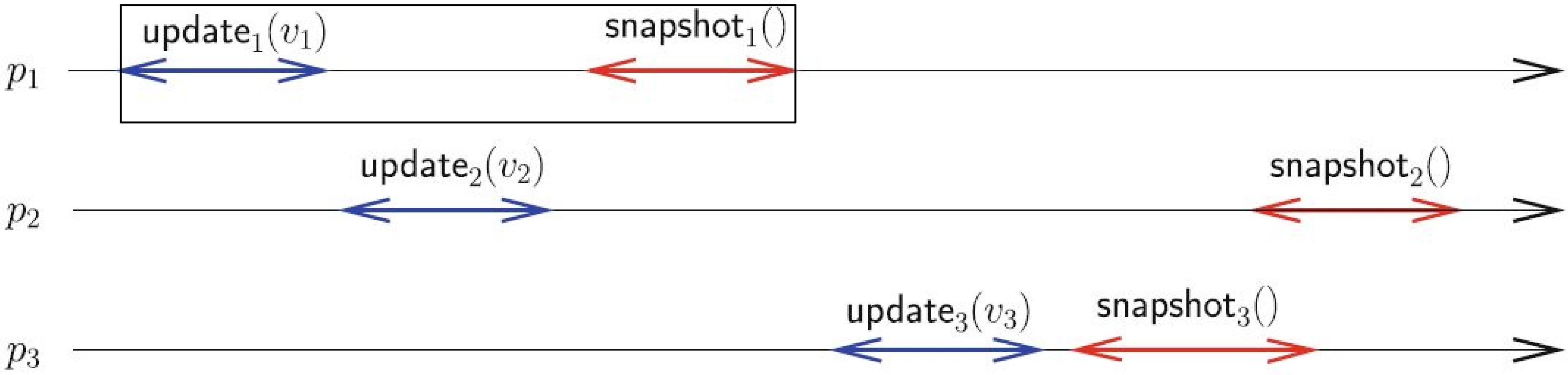
n processes share an atomic snapshot object x

update_snapshot(vi):

- x.update(i, vi);
- a := x.scan();
- Return {(1, a[1]), (2, a[2]), …, (n, a[n])}

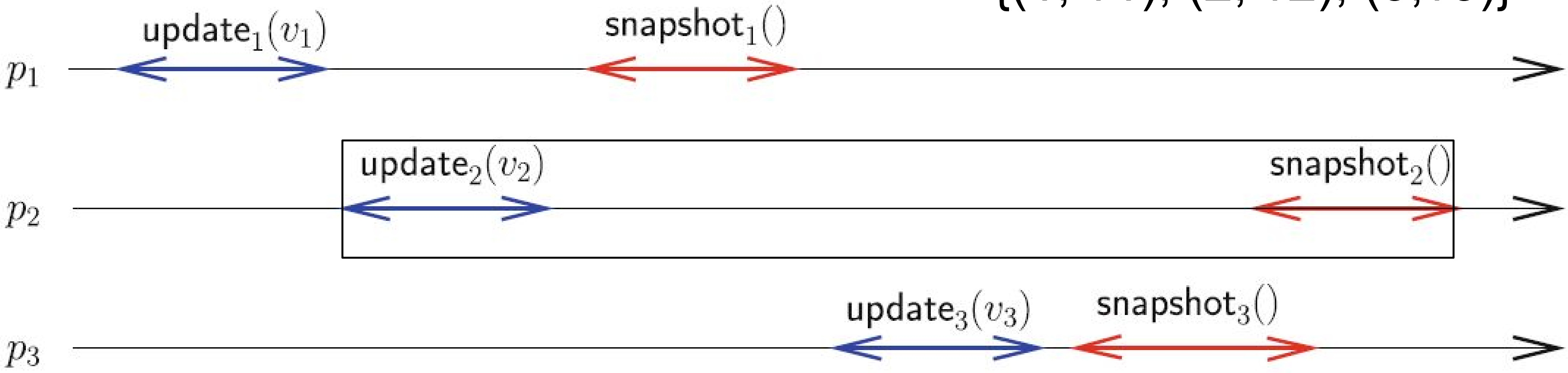
Immediacy?

update_scan() - {(1, v1), (2, v2)}



Immediacy?

update_scan()
- {(1, v1), (2, v2), (3,v3)}



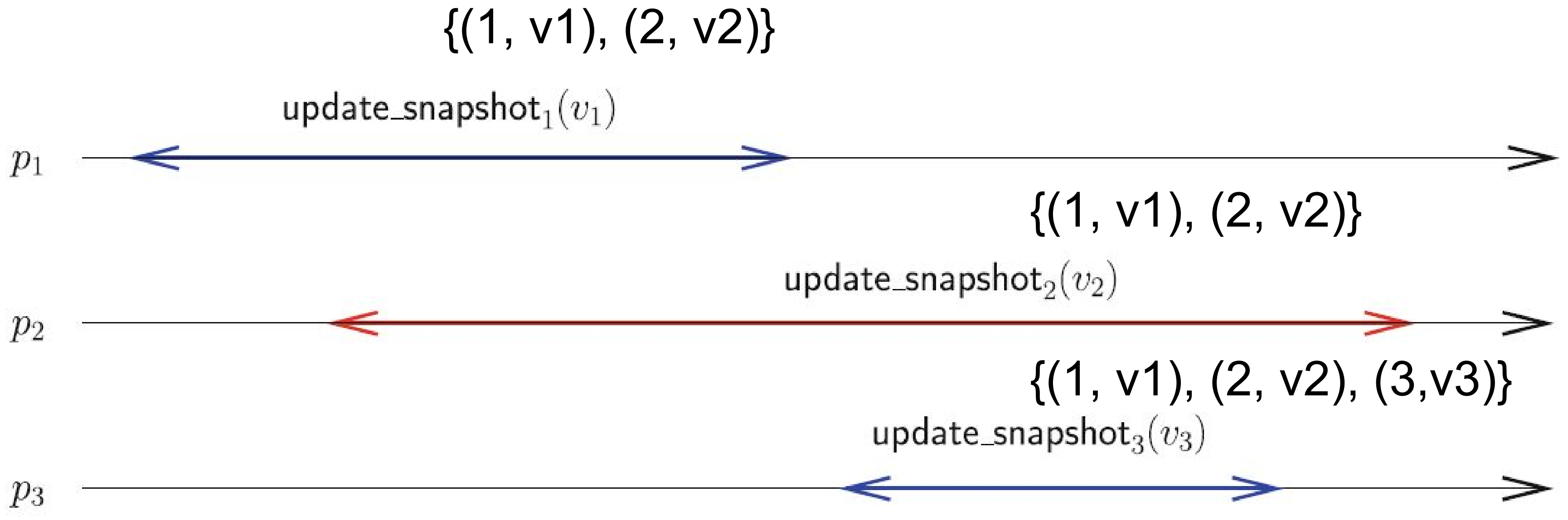
Snapshot vs. immediate snapshot

An atomic snapshot

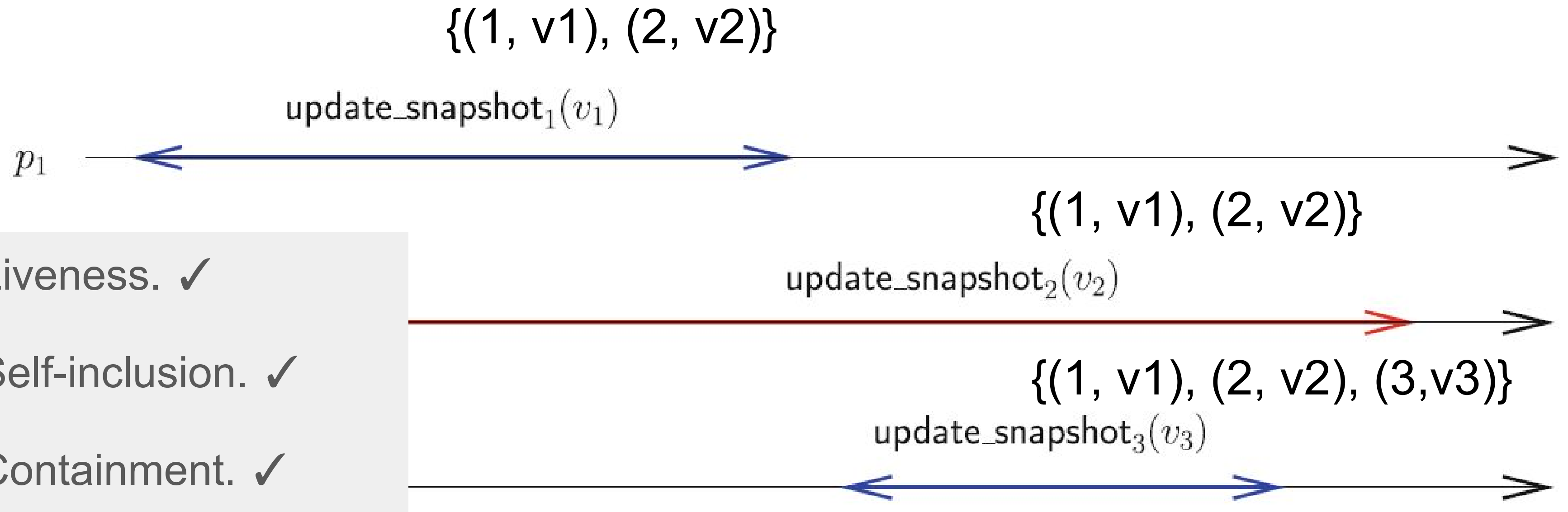
An immediate snapshot that satisfies

- Liveness, self-inclusion, containment, immediacy

Possible execution?



Possible execution?



Liveness. ✓

Self-inclusion. ✓

Containment. ✓

Immediacy. ✓

A property that follows

(Self-inclusion. (i, vi) ∈ viewi

+ Immediacy. If (j, vj) ∈ viewi, then viewj ⊆ viewi)

Property: If (i, -) ∈ viewj and (j, -) ∈ viewi, then viewj = viewi

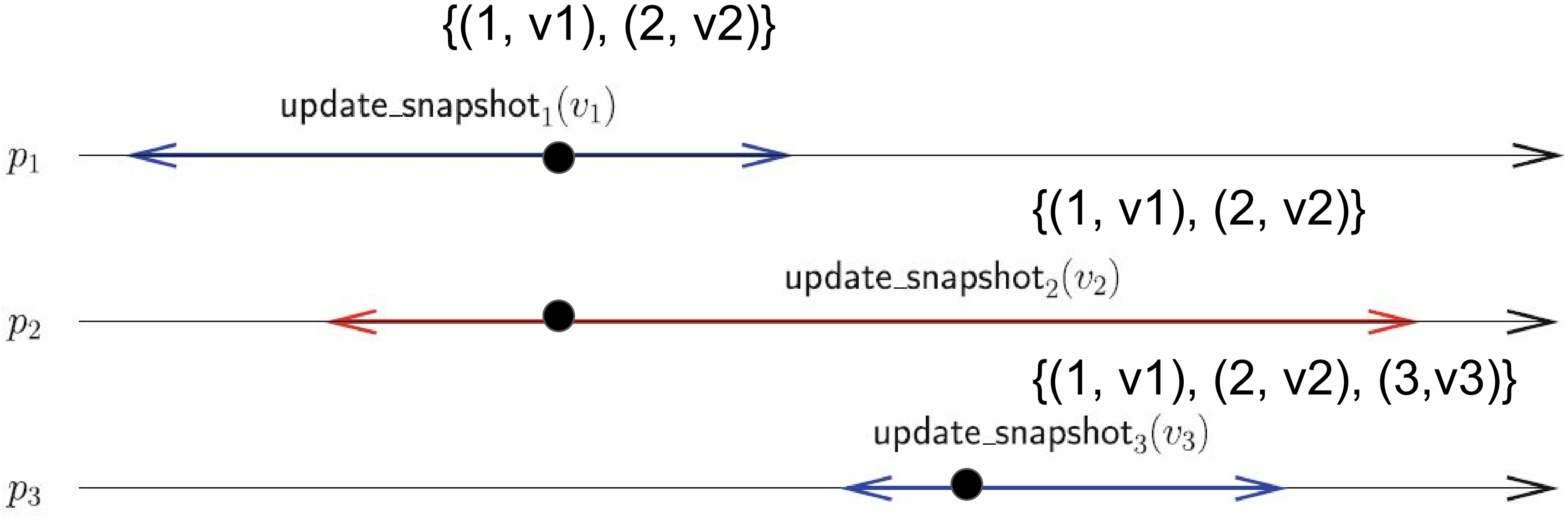
=> Compared with sequential execution?

Atomicity

Every operation appears to execute at

- Some indivisible point in time (called linearization point) between
- The invocation and reply time events

Atomic execution?



Set linearizability

Linearization replaced by set-linearization:

- These invocations are set-linearized at the same point of the time line

For one-shot immediate snapshot,

- The invocations which are set-linearized at the same point do return the very same view

Key idea for set linearizability

To ***update_scan()***, a process keeps reading other processes' updates

For any two processes pi and pj,

- If pi and pj see each other's update, then pi and pj retry reading until they are going to return the **same** result

Enforcing set linearizability

The processes share an array of ***registers*** REG[1], REG[2], REG[3], …

- REG[x] is again an array of registers
- REG[x] contains a view
- REG[x][i] can only be written by pi

Pi reads REG[x]

- If pi cannot return REG[x], then pi retries, writes and reads the **next** REG

Enforcing set linearizability

The processes share an array of ***registers*** REG[1], REG[2], …, init'ed to ⊥

A recursive implementation:

- ***update_snapshot(vi):***
    - my_viewi := rec_update_snapshot(**next**, vi)
    - Return my_viewi

Enforcing set linearizability

Every process keep a local array of registers Regi

- ***rec_update_snapshot(x, v):***
    - REG[x][i].write(v);
    - For each j ∈ {1,..., n} do Regi[j] := REG[x][j].read();
    - Viewi := { (j, Regi[j]) | Regi[j] ≠ ⊥};
    - if(**some condition**) then resi := viewi;
    - Else resi := rec_update_snapshot(**next**, v);
    - Return resi

Possible execution?

	REG[1]	REG[2]	REG[3]	...	
p1	v1	v1	v1		
p2	v2	v2	v2		
p3		v3	v3		

Key idea for liveness

If pi and pj see each other’s update, then pi and pj retry

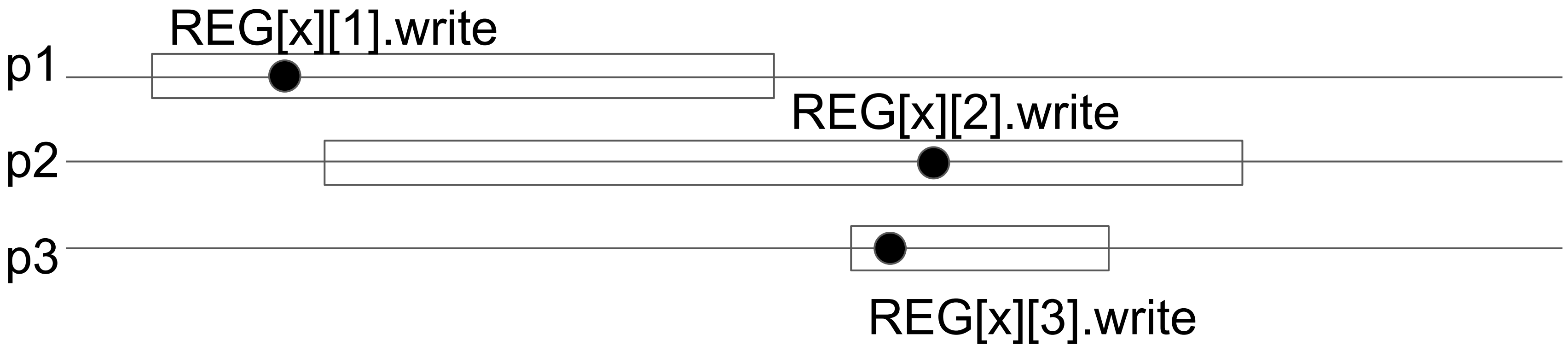
- Pi is waiting for pj’s last-minute view
- So is pj
- Which view is the last one?

Key idea for liveness (cont'd)

Suppose: At most x processes access REG[x] (invariant)

If pi sees REG[x] contains exactly x updates, then

- pi is one of the **last** processes which accesses REG[x]
- Or linearized as such



Key idea for liveness (cont'd)

Suppose: At most x processes access REG[x] (invariant)

If pi sees REG[x] contains exactly x updates, then

- pi is one of the **last** processes which accesses REG[x]
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If the invariant is true, then after pi, REG[x] remains the **same**.

Key idea for liveness (cont’d)

Suppose: At most x processes access REG[x] (invariant)

If pi sees REG[x] contains exactly x updates, then

- pi is one of the **last** processes which accesses REG[x]
- Or linearized as such

If the invariant is true, then after pi, REG[x] remains the **same**

- Pi can return REG[x]
- As well as other processes who see pi’s update

Key idea for set-linearizability & liveness

Recall that we consider one-shot version:

- Each process invokes at most once ***update_scan()***
- This means at most n processes access the **first** REG

Key idea for set-linearizability & liveness

Recall that we consider one-shot version:

- Each process invokes at most once ***update_scan()***
- This means at most n processes access the **first** REG = REG[n]

If **some condition** = a process's view of REG[n] contains n values, then

- Return REG[n]
- Otherwise, go to the **next** REG = REG[n-1]

Key idea for set-linearizability & liveness (cont'd)

The processes share an array of ***registers*** REG[n], REG[n-1], …, REG[1]

- Each contains a view

Claim:

(a) At most x processes can access REG[x]
(b) At least one process return REG[x]

Immediate snapshot implementation

- ***update_snapshot(vi):***
  - my_viewi := rec_update_snapshot(n, vi)
  - Return my_viewi

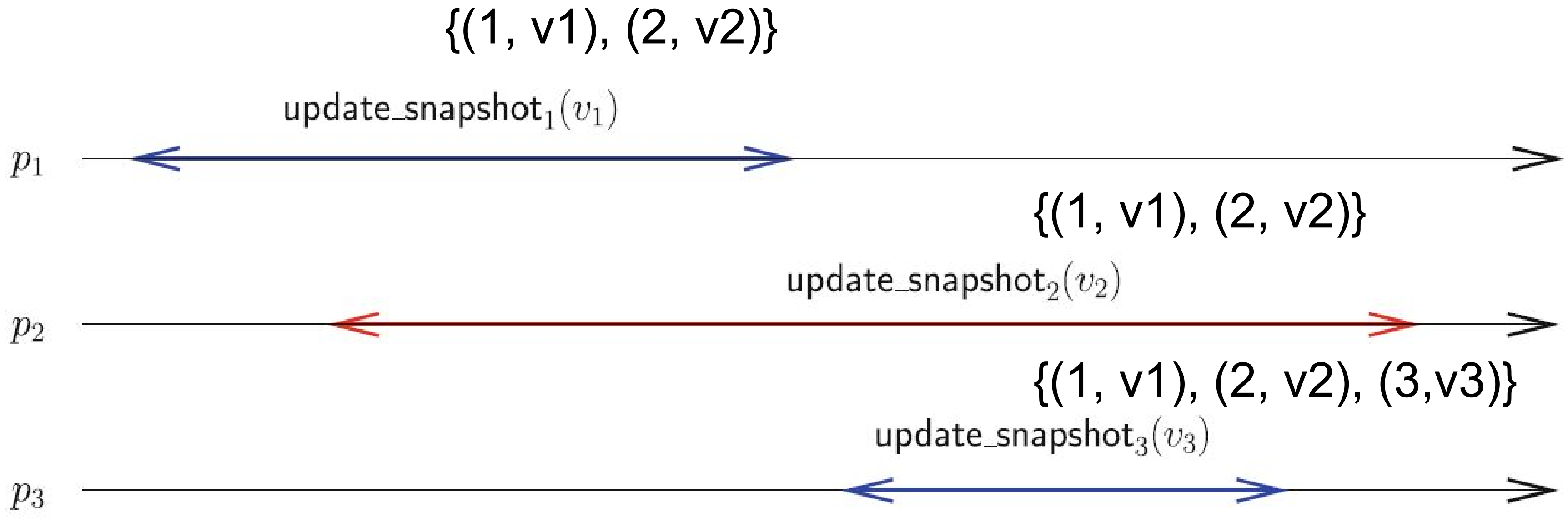
Immediate snapshot implementation

The processes share an array of ***registers*** REG[1, …, n], init'ed to ⊥

Every process keeps a local array of registers Regi

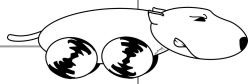
- ***rec_update_snapshot(x, v):***
  - REG[x][i].write(v);
  - For each j ∈ {1,..., n} do Regi[j] := REG[x][j].read();
  - Viewi := { (j, Regi[j]) | Regi[j] ≠ ⊥};
  - if(|viewi| = x) then resi := viewi;
  - Else resi := rec_update_snapshot(x-1, v);
  - Return resi

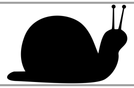
Possible return value?



Possible execution?

	REG[n]	REG[n-1]	...	REG[3]	REG[2]
p1	v1	v1	...	v1	v1
p2	v2	v2	...	v2	v2
p3	v3	v3	...	v3	





References

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[2] Raynal M. (2013) Snapshot Objects from Read/Write Registers Only. In: Concurrent Programming: Algorithms, Principles, and Foundations. Springer, Berlin, Heidelberg