Distributed computing on mobile tiny devices

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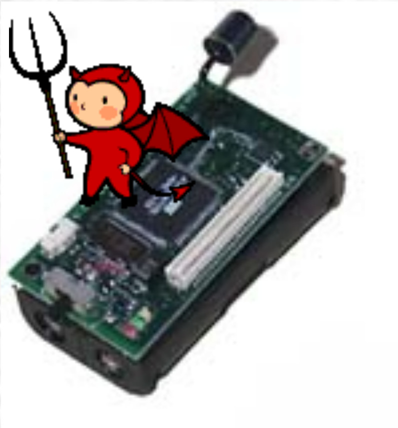
A world of tiny mobile devices



What computing model?

Overview

(1) Mobility

(2) Crashes

(3) Privacy

(4) Security

The march of the penguins

The march of the penguins

- The group is threatened if more than a threshold dies on the way back to the sea
- If a penguin starts its trip with a very low temperature, the probability that it reaches the sea is very low

The escort

- Provide each penguin with a computing device to:
  - measure its temperature;
  - trigger an alert if a threshold (say 5) has a very low temperature

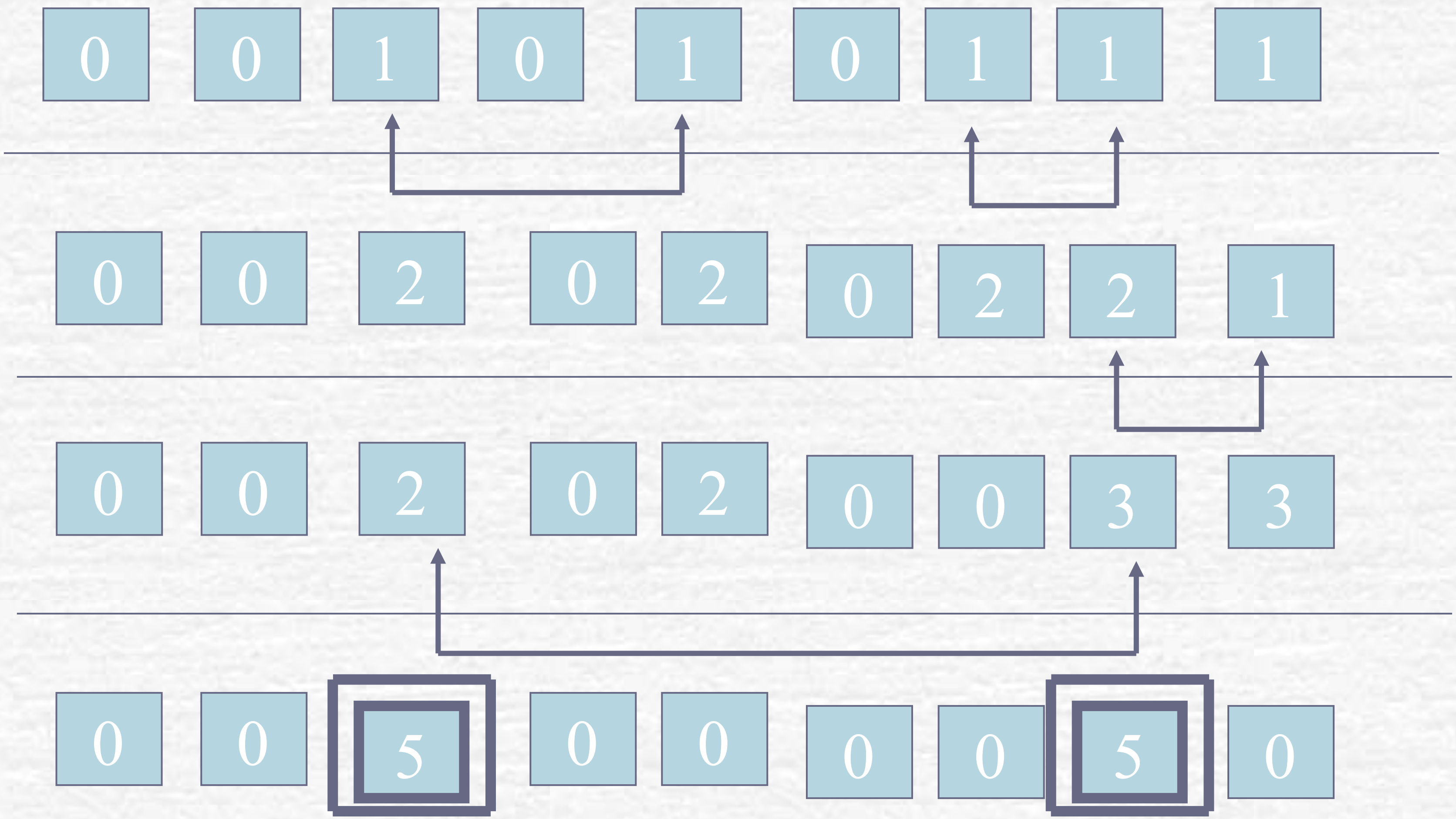
Assumptions

- Every device holds a finite counter (<6)
  - Its initial value is 1 if the penguin has a low temperature and 0 otherwise
- A pair of devices communicate if they get close enough
  - Every pair of devices eventually meet

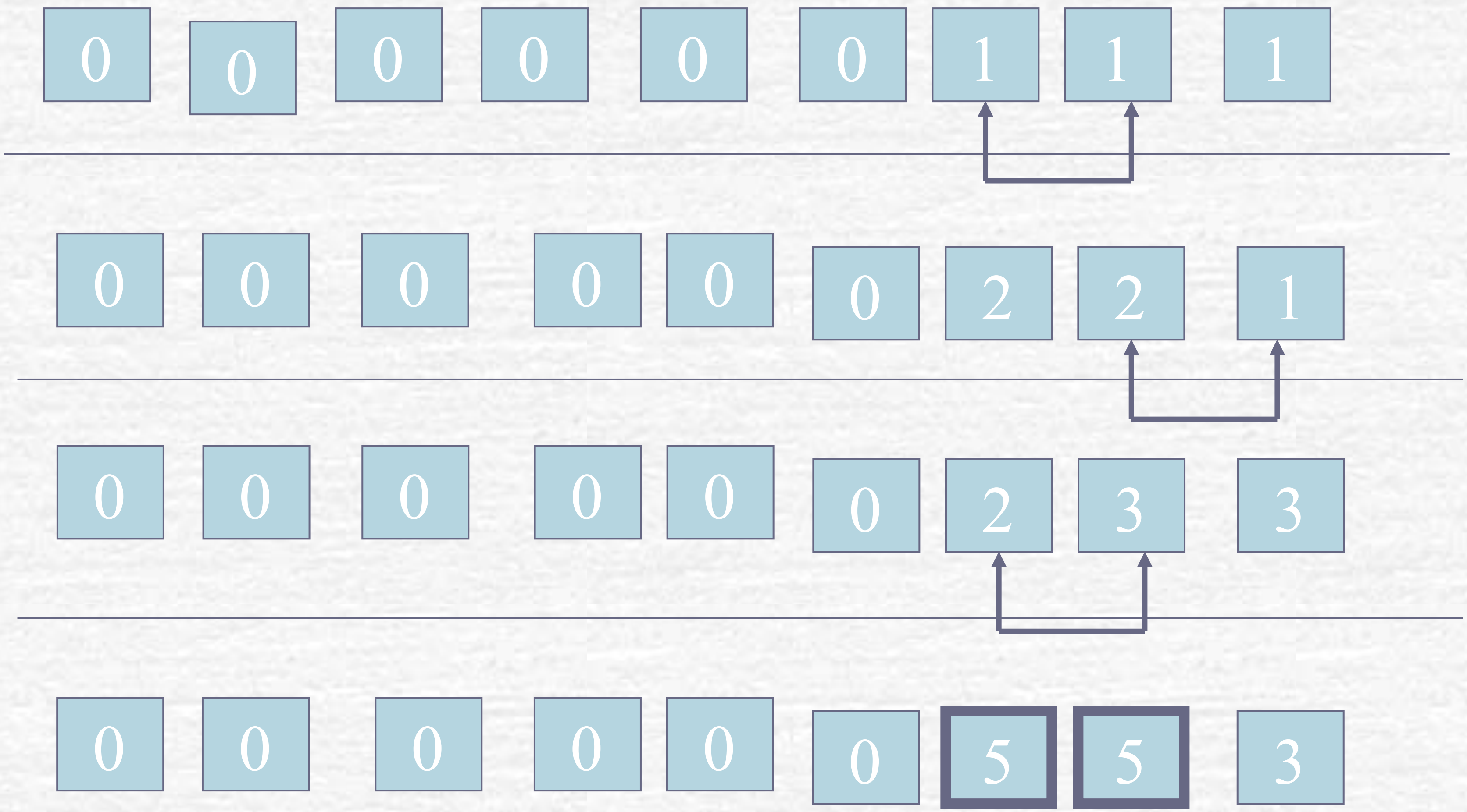
The problem

- All devices eventually output “alert” iff at least 5 initial values are 1

Algorithm ?



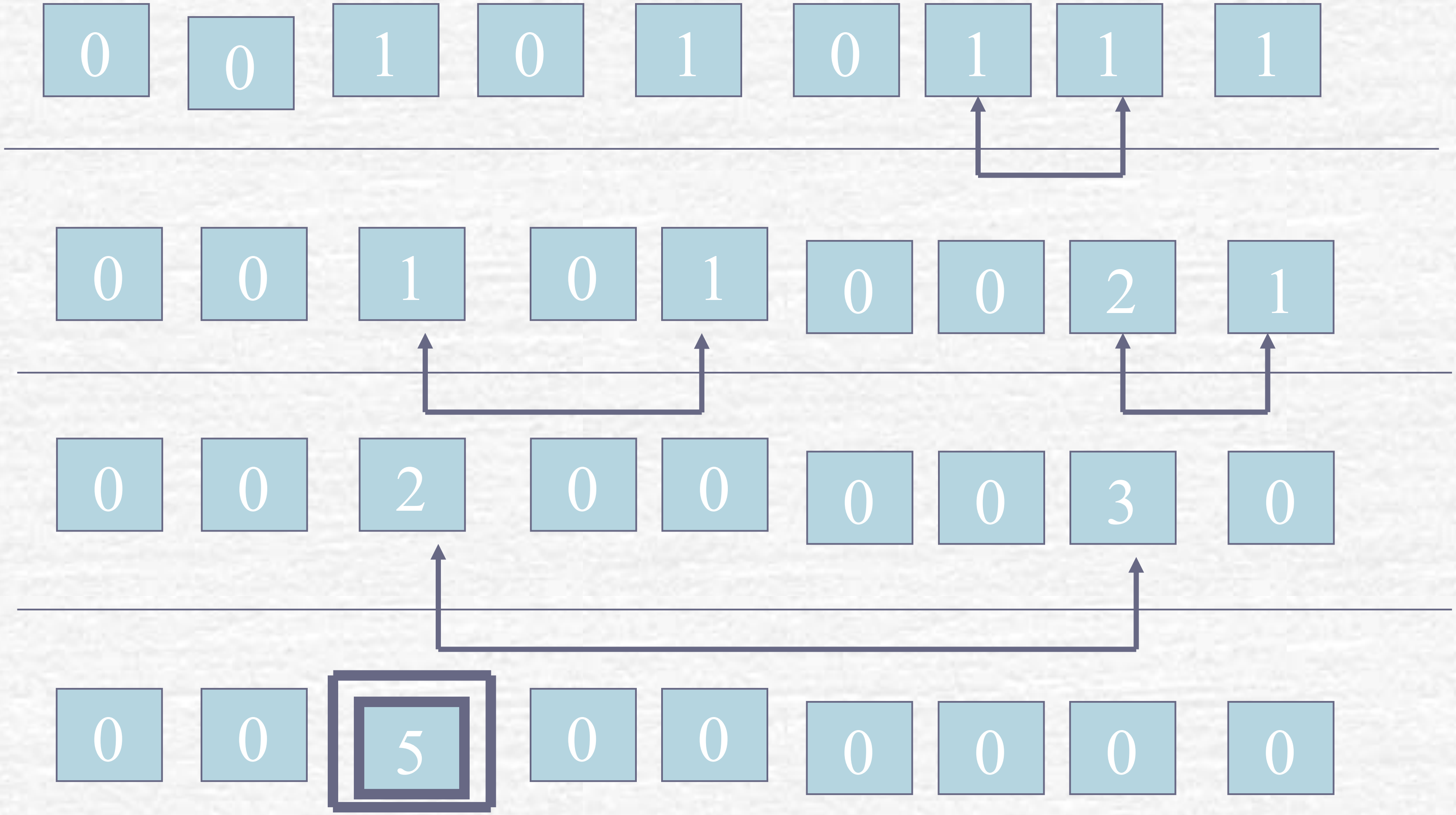
Algorithm?



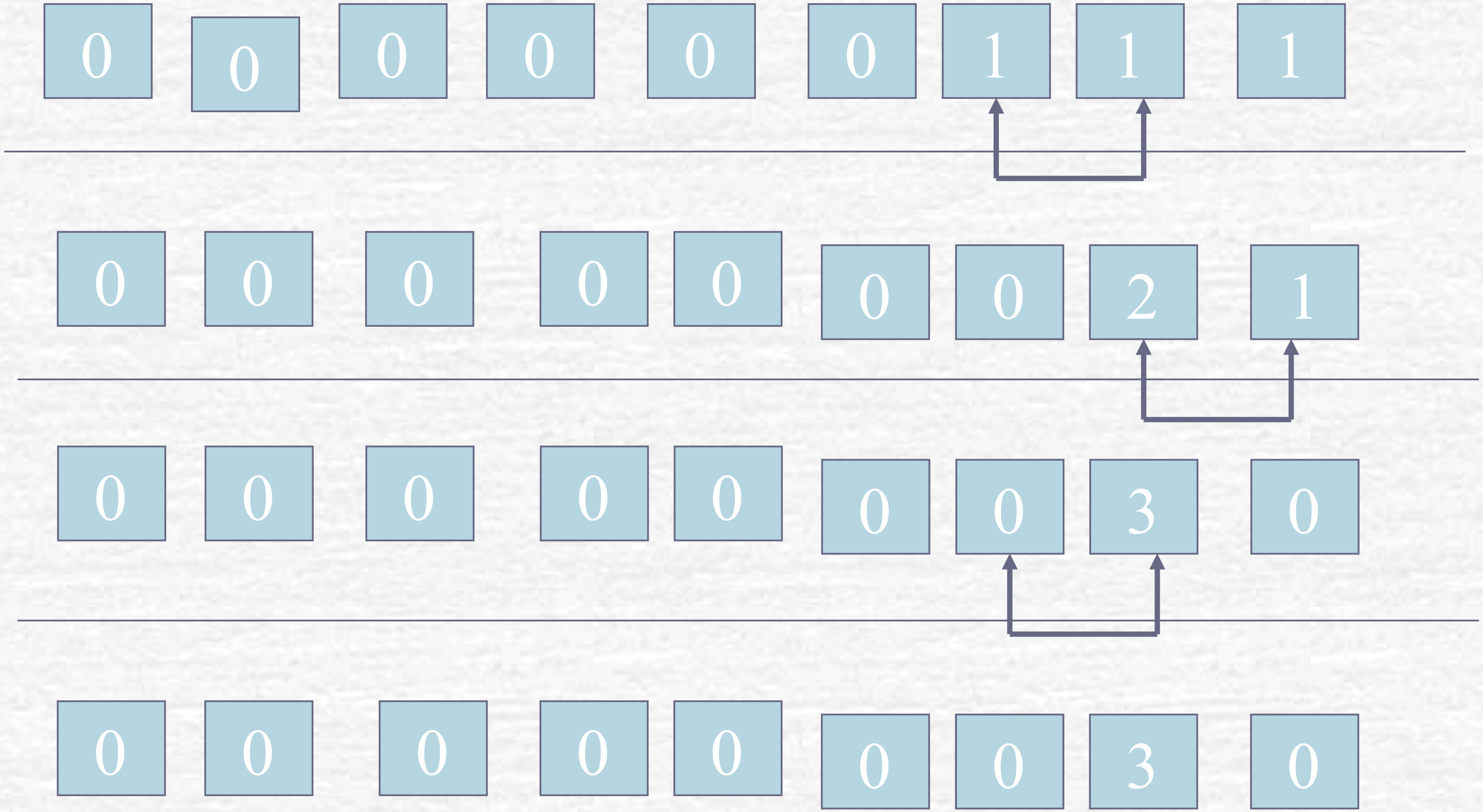
Algorithm

- When two devices meet, one keeps in its counter the sum of the values whereas the other puts it back to 0
- Any device with value 5 triggers the alert

Algorithm



Algorithm



Population protocols (DF01,AADFP’04)

- A population $\mathbf{P}$ is a set of ***agents***
- Every agent has a ***bounded*** memory independent of the size of the system
- Algorithms are ***uniform*** and ***anonymous***

Population protocols

- The agents are ***asynchronous*** and have no control over their ***mobility*** pattern
- A pair of agents communicate if they get ***close*** to each other (one is the ***initiator***)
- Every interaction that is always possible eventually happens (***fairness***)

Population protocol

- Input; Output; State S
- InMap In; OutMap Out
- Transition δ

Configuration / Execution

- A ***configuration*** is a set of states of all agents
- An ***execution*** is a sequence of configurations

Fairness

- An infinite execution E is ***fair*** if for any transition δ(C,C′), if C appears infinitely in E, then C′ appears infinitely in E

- A ***computation*** is a fair execution

Stability and convergence

- A configuration C is ***stable*** if for every C′ such as δ(C,C′), we have: Out(C) = Out(C′)

- An infinite execution ***converges*** if it has a stable configuration

Back to the Penguins

- Input = {0,1}
- Output = {ALARM, OK}
- S = {0,1,2,3,4,5}
- In (identity): 0 → 0, 1 → 1
- Out:{0, 1, 2, 3, 4} → OK

  5 → ALARM

Transition

- $\delta: (i, j) \rightarrow$ $(i+j, 0)$ if $i+j < 5$
  $(5, 5)$ if $i+j \geq 5$

More generally (AAD06)

- ***Theorem: population protocols compute exactly first order Presburger's arithmetic: +, -, =, >, or, not, and, …***
- NB. Not as powerful as Peano's arithmetic which also include *

Overview

(1) Mobility

(2) Crashes

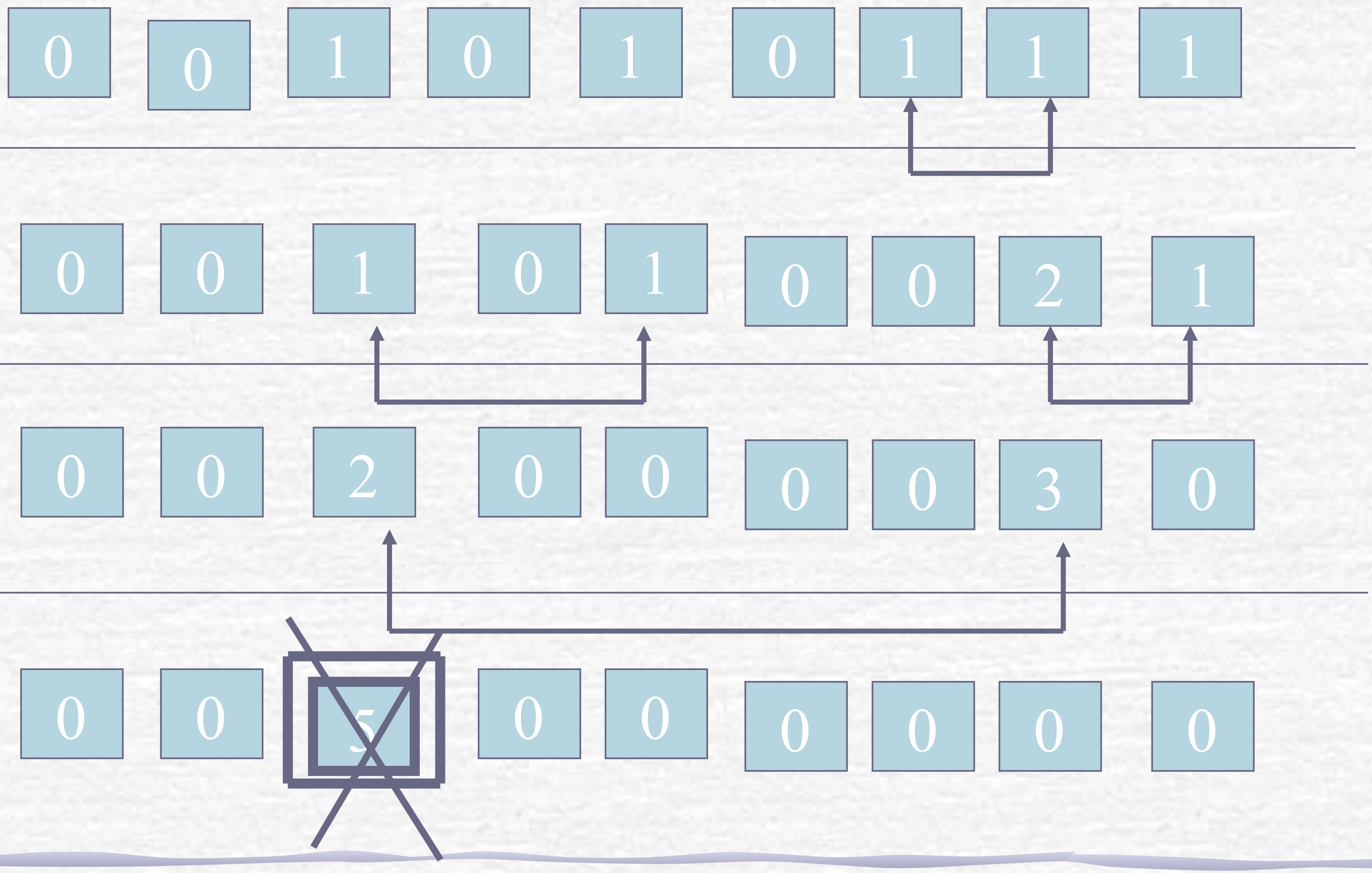
(3) Privacy

(4) Security

But what if?

- One of the agents fail (say by crashing at some inappropriate time)
- An agent might crash exactly when it reaches value 4

Original algorithm O

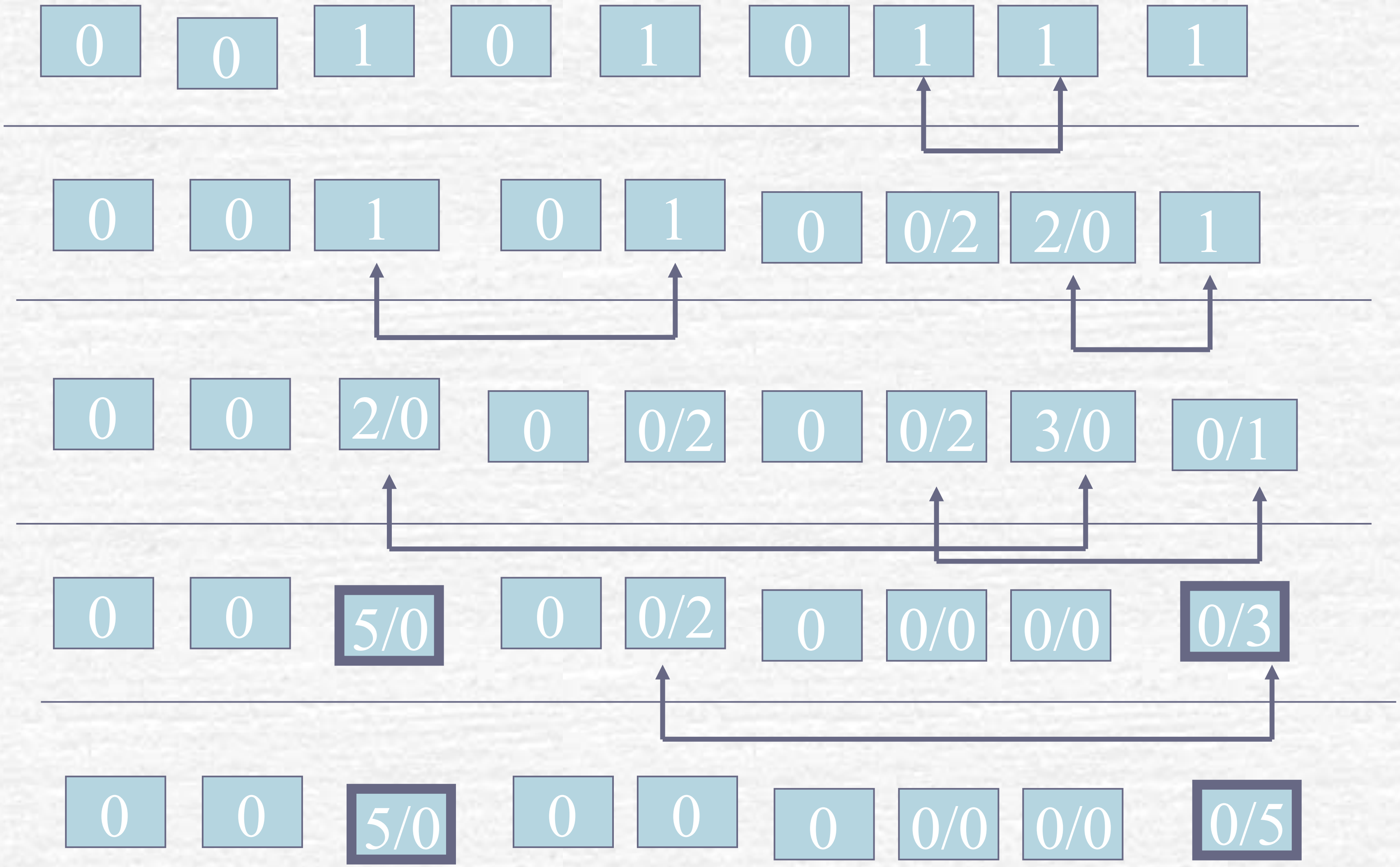


Reliable algorithm

- Every agent performs ***twice*** the original algorithm: O1 and O2

- When two agent communicate, one acts as the initiator for O1 and the other as the initiator for O2

Reliable algorithm



More generally (DFGR06)

- Theorem: population protocols compute exactly Presburger's arithmetic with a constant number of crashes
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This talk

(1) Mobility

(2) Crashes

(3) Privacy

(4) Security

What about privacy?

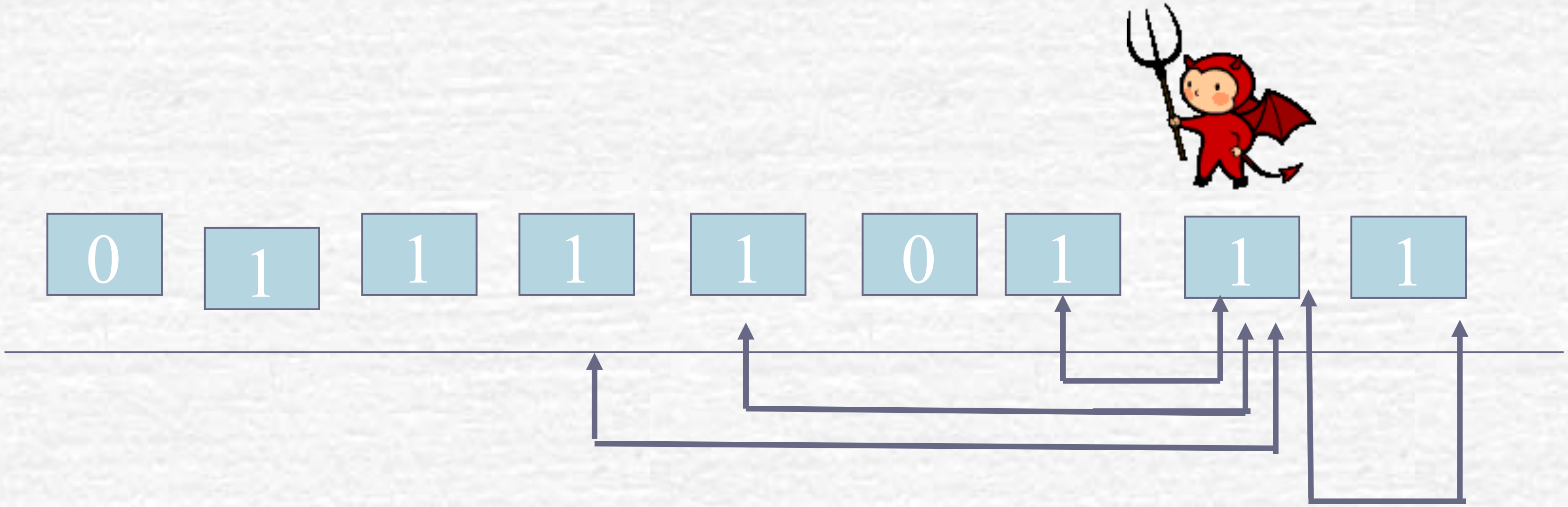
- How can we ***hide*** the initial values from curious agents?

- How can we compute a result while preventing any agent from figuring out, at any point in time, any information besides its own input and the result of the computation?

What about privacy?

- How can we make it impossible for a curious agent to distinguish the situation where exactly 5 penguins have low temperature from the situation where more do?

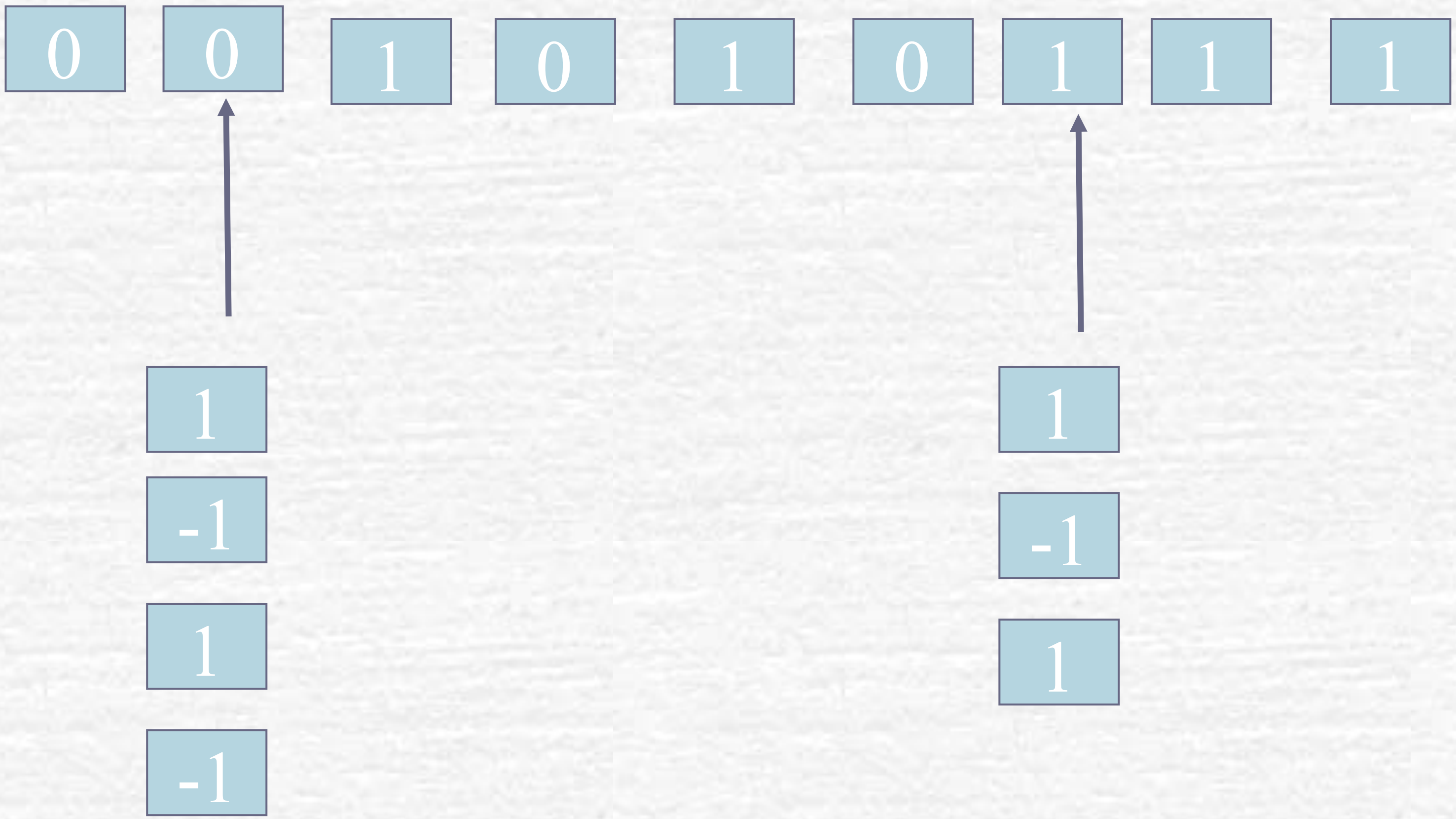
Original algorithm



How to ensure privacy?

- An agent cannot use crypto (not even signatures because of anonymity)
- An agent can see the entire state of the agent it is interacting with: hence no secret keys are possible

Obfuscation



More generally (DFGR07)

- Theorem: population protocols can privately compute exactly first order Presburger's arithmetic

This talk

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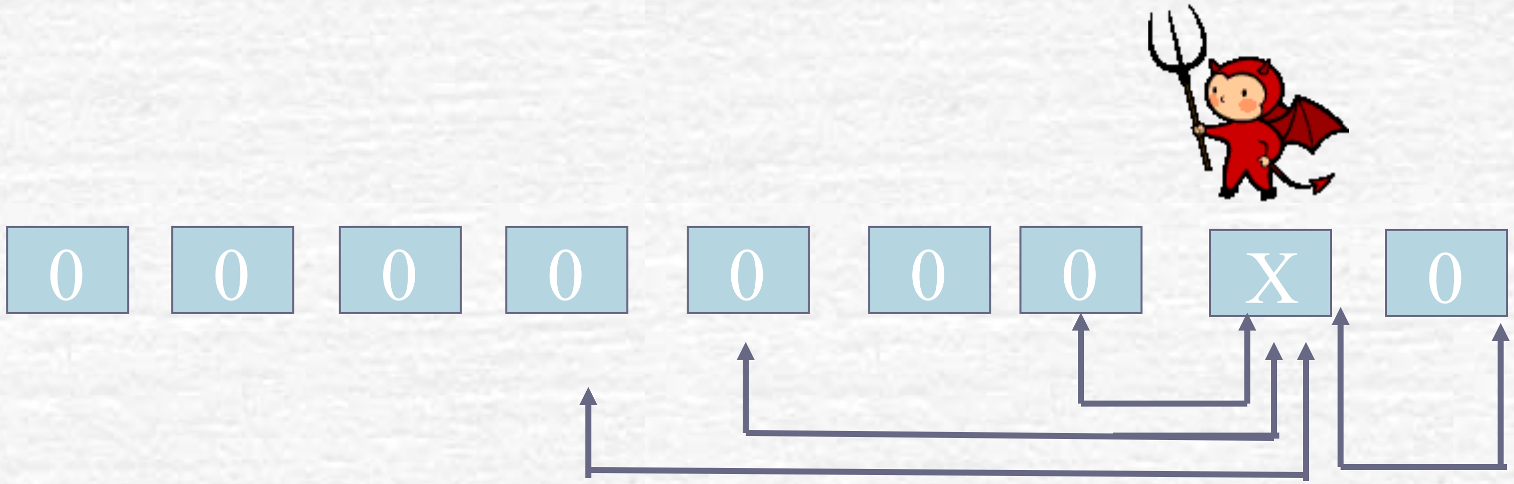
What if agents can be malicious?

- What can we compute with one malicious agent? (arbitrary transitions)

Malicious agent



More generally (GR07)

- ***Theorem: population protocols cannot compute any non-trivial predicate with a single malicious agent***
- NB. A predicate is ***trivial*** if every agent can determine its output based only on its input

Community protocols (GR07)

- Every agent has:
  - A bounded memory where it can execute arithmetics (as in the original population model)

  +

  - A bounded set of slots to store identities and test (only) for their equality

Community protocols (GR07)

- ***Theorem***: ***community protocols*** can exactly compute every ***symmetric*** predicate that can be (Turing) computed in ***n log n*** space