Addressing False Causality while Detecting Predicates in Distributed Programs

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Introduction

Predicate Detection:

Does a global condition occur in a distributed computation?

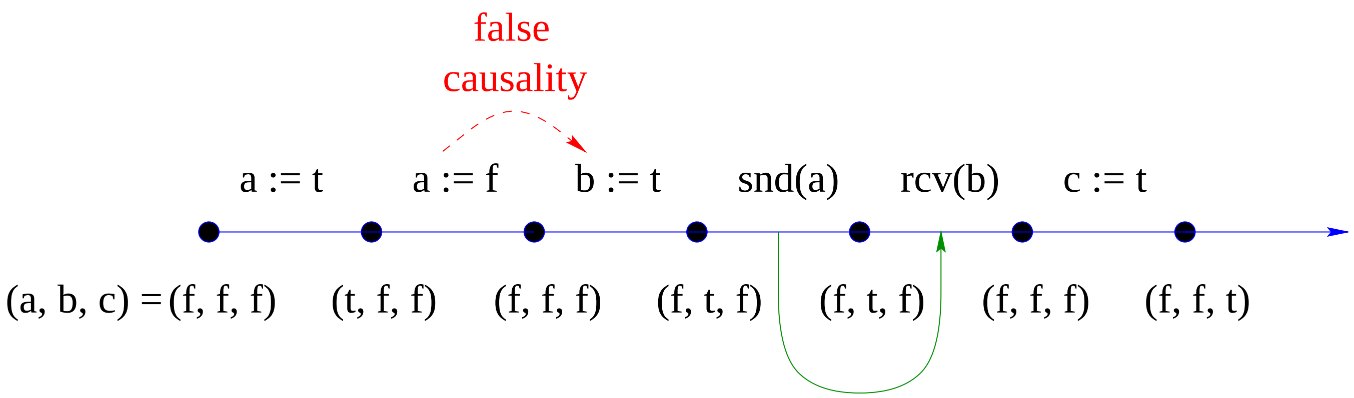
Some Applications:

- distributed debugging: global bugs
  Example: Is mutual exclusion violated? $(CRIT_1 \wedge CRIT_2)$
- fault-tolerance: global faults
  Example: Has a token been lost? $(\neg TOK_1 \wedge \neg TOK_2)$

Goals

- The need for a new model of distributed computations
- Our results in solving predicate detection in the new model

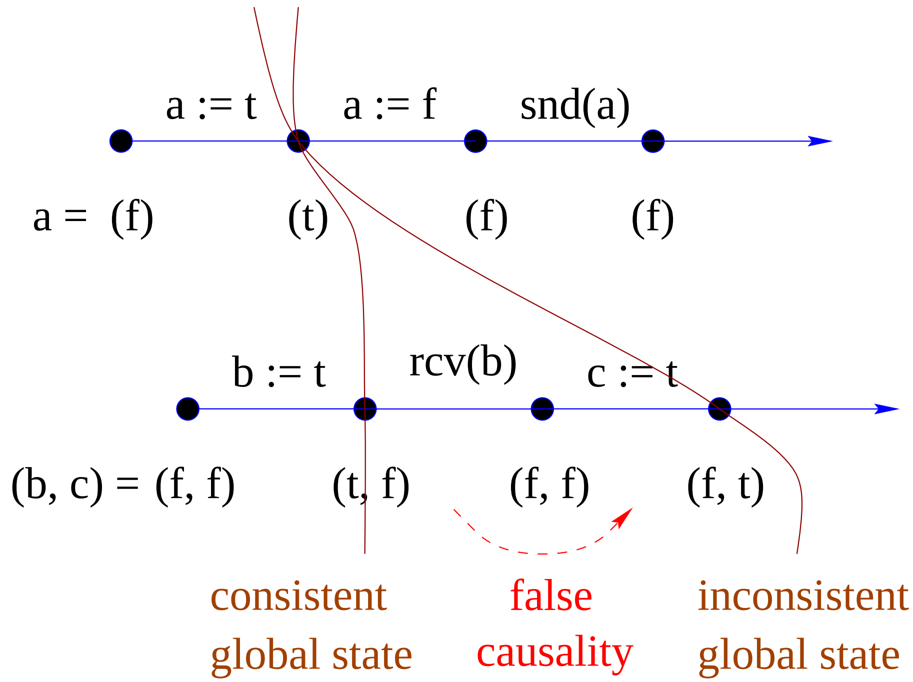
The Interleaved Model



computation, state, event

detect predicate: $(a \wedge b)$

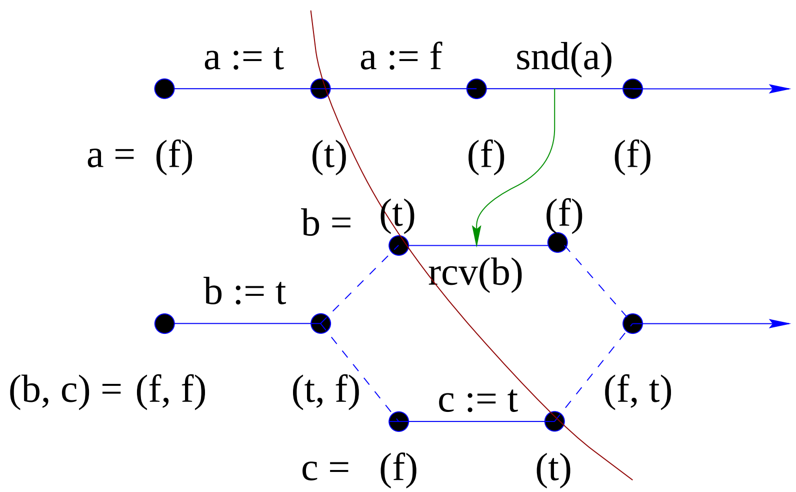
The Happened-Before Model



global state, happened-before, consistent global state

detect predicates: $(a \wedge b)$, $(a \wedge c)$

The Strong Causality Model



global state, strong causally precedes, consistent global state

detect predicate: $(a \ \wedge \ c)$

Independent Events

- Multi-threading:

```
create_thread(thread_1);          thread_1() :
c := t;
wait(thread_1);                       rcv(b);
```

- Independent Actions:

```
c := t  ||  rcv(b)
```

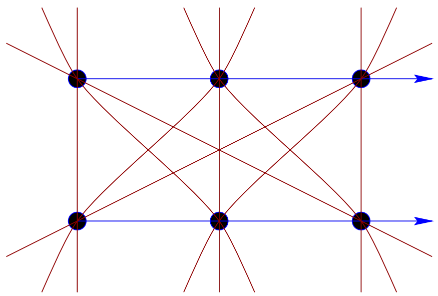
- Non-blocking receives:

```
x := rcv(b, NON_BLOCK);
c := t;
if (¬ x) then
    rcv(b);
```

Predicate Detection in the Happened-Before Model

... is difficult (NP-Complete) [Chase, Garg 95]

Intuition: too many global states!



$3^2 = 9$ global states

In general, $O(m^n)$ global states, where:

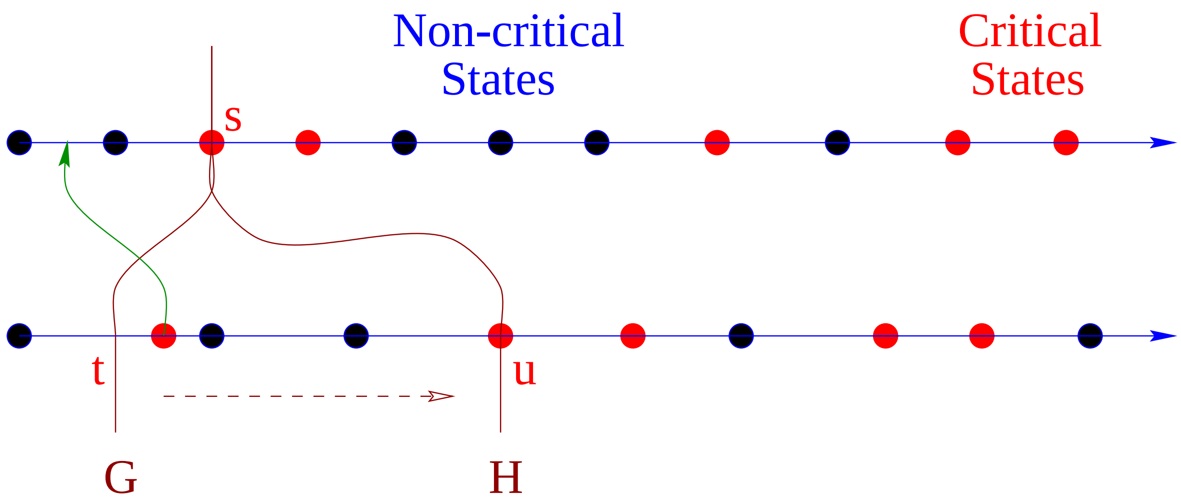
m is the number of states in a process, and

n is the number of processes

Predicate Detection in the Happened-Before Model

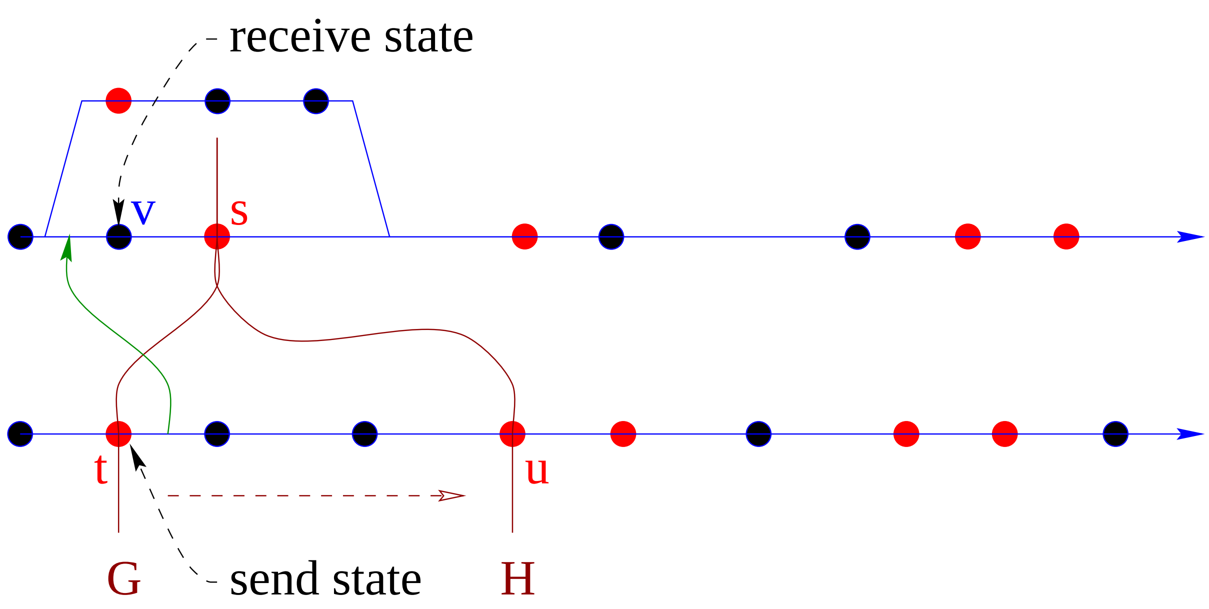
Conjunctive Predicates: [Garg, Waldecker 94]

Are two processes critical together? $(CRIT_1 \wedge CRIT_2)$



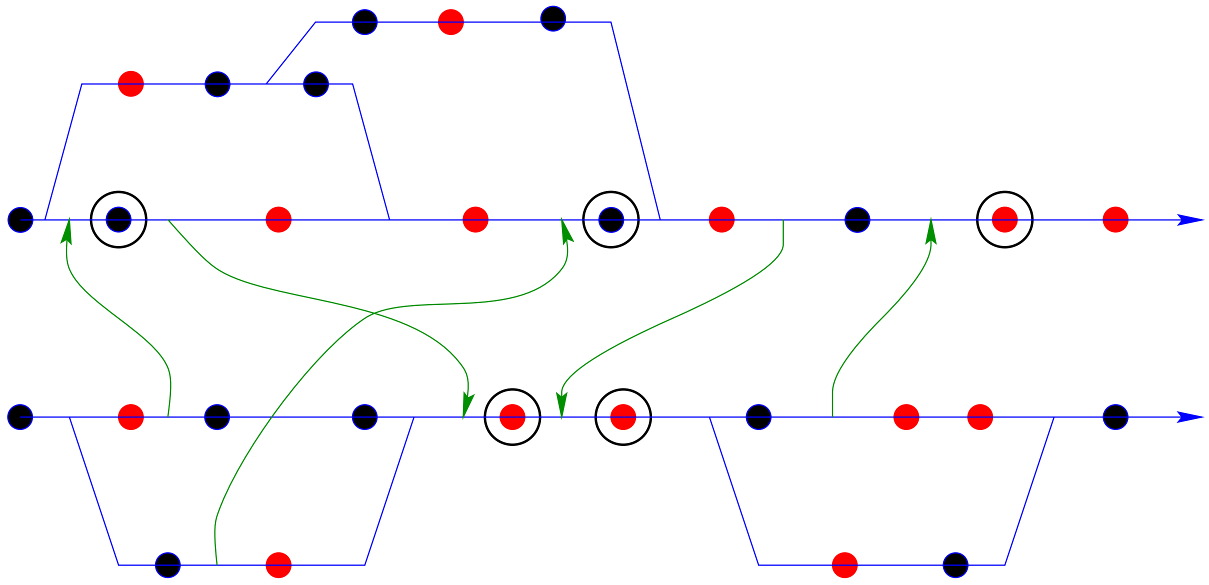
Predicate Detection in the Strong Causality Model

... is difficult even for Conjunctive Predicates (NP-Complete)



Receive-ordered Computations

totally ordered receive states

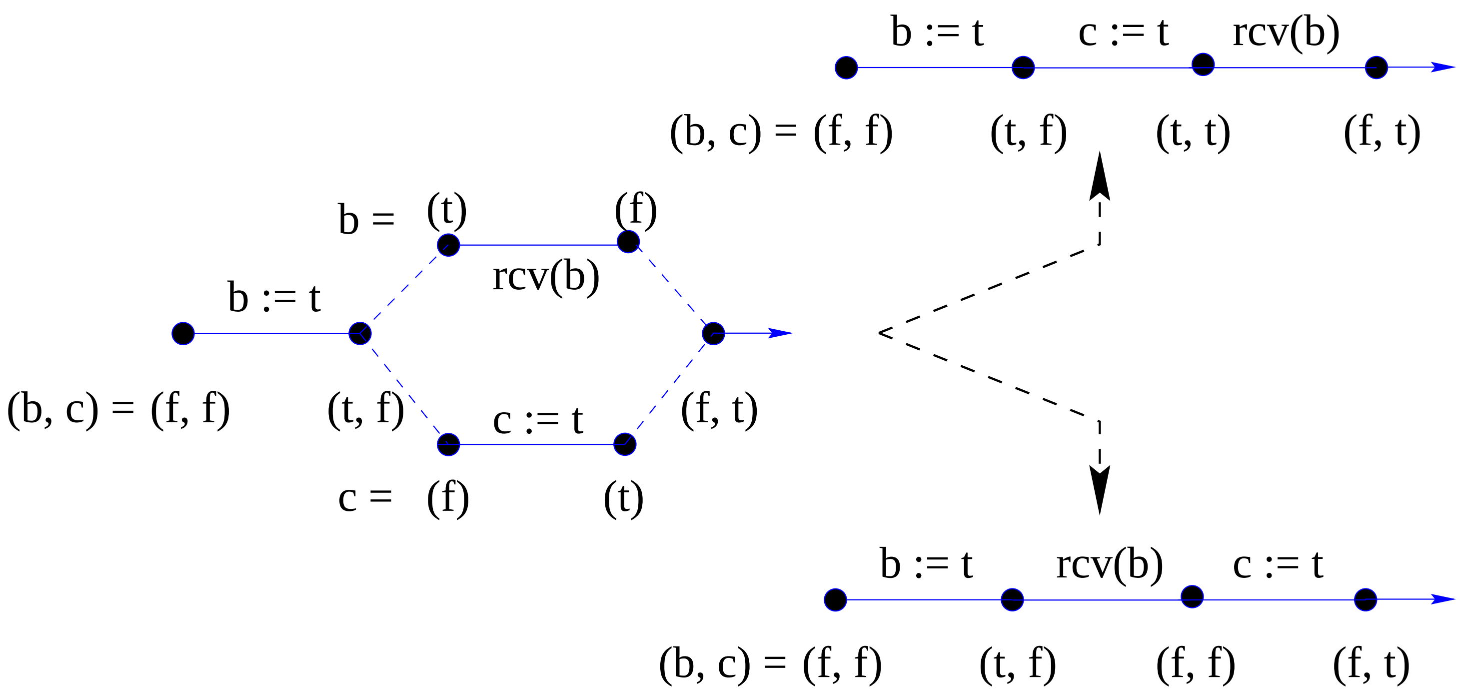


Receive-ordered Computations

Example: Multi-threaded Server

```
repeat
    receive a request;
    create a thread to process the request
until done
```

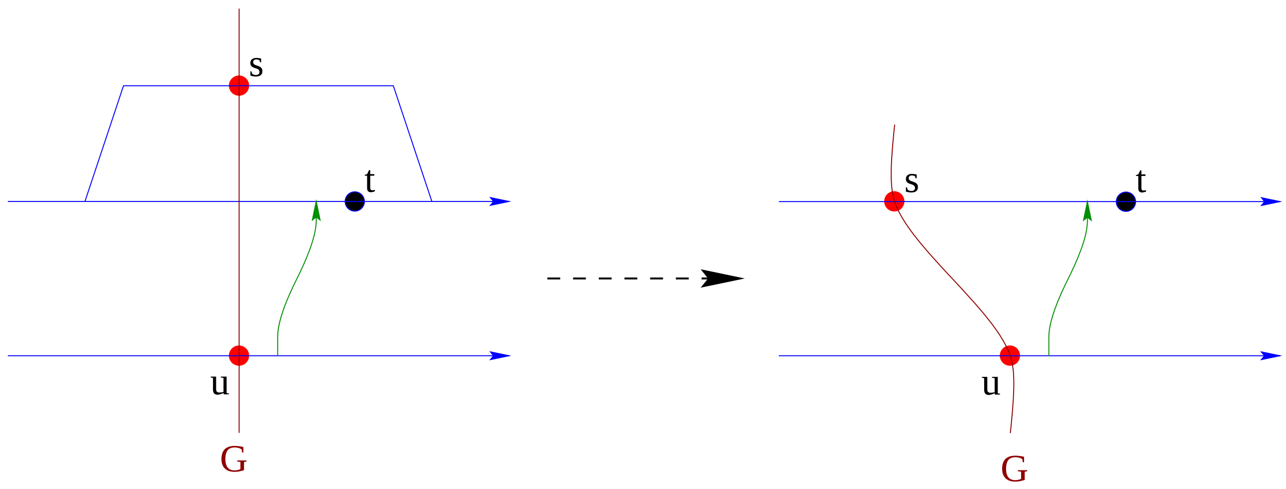
Linearizing a computation



Predicate Detection in Strong Causality Model

Key observation:

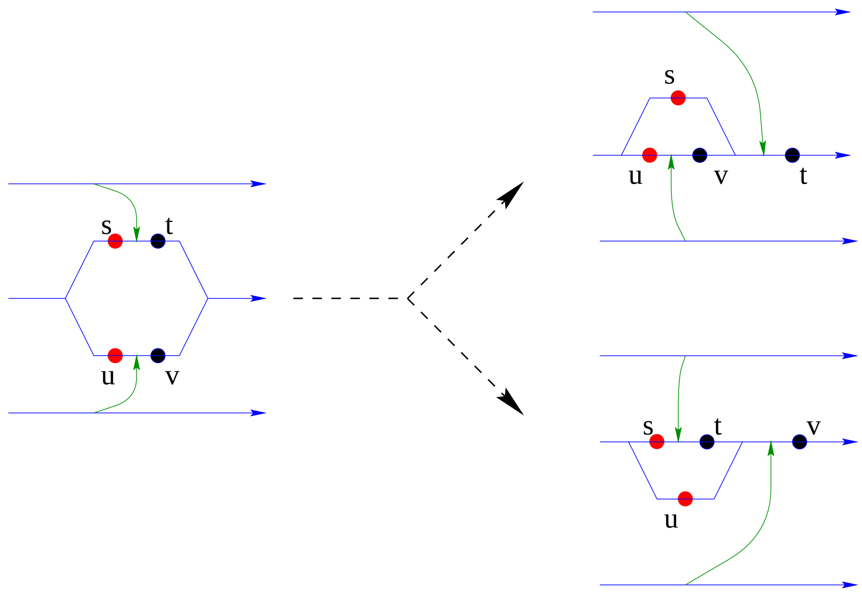
linearize each process's computation ensuring that receive states are ordered after all concurrent states



we can now apply predicate detection as before!

Predicate Detection in Strong Causality Model

Another look at general (not receive-ordered) computations:



There are an exponential number of receive-ordered computations.

But the alternative – interleaved computations – is exponentially worse.

Conclusions

- The need for a new model of distributed computations
  - modeling local independent events
  - detecting more predicates (more bugs!)
- Our results in solving predicate detection in the new model
  - Conjunctive predicate detection is NP-Complete
  - Efficient algorithm for receive-ordered computations
  - Exponential saving for general computations

Also: send-ordered computations