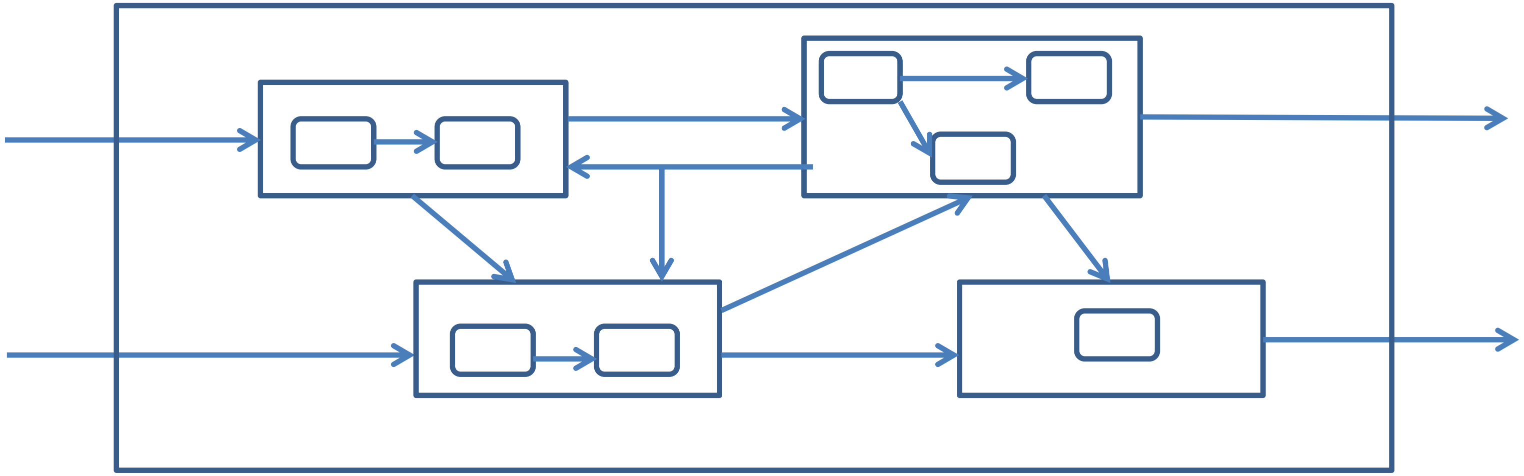
CS:5980
Foundations of Embedded Systems

The Synchronous Model
Part III

Synchronous Design



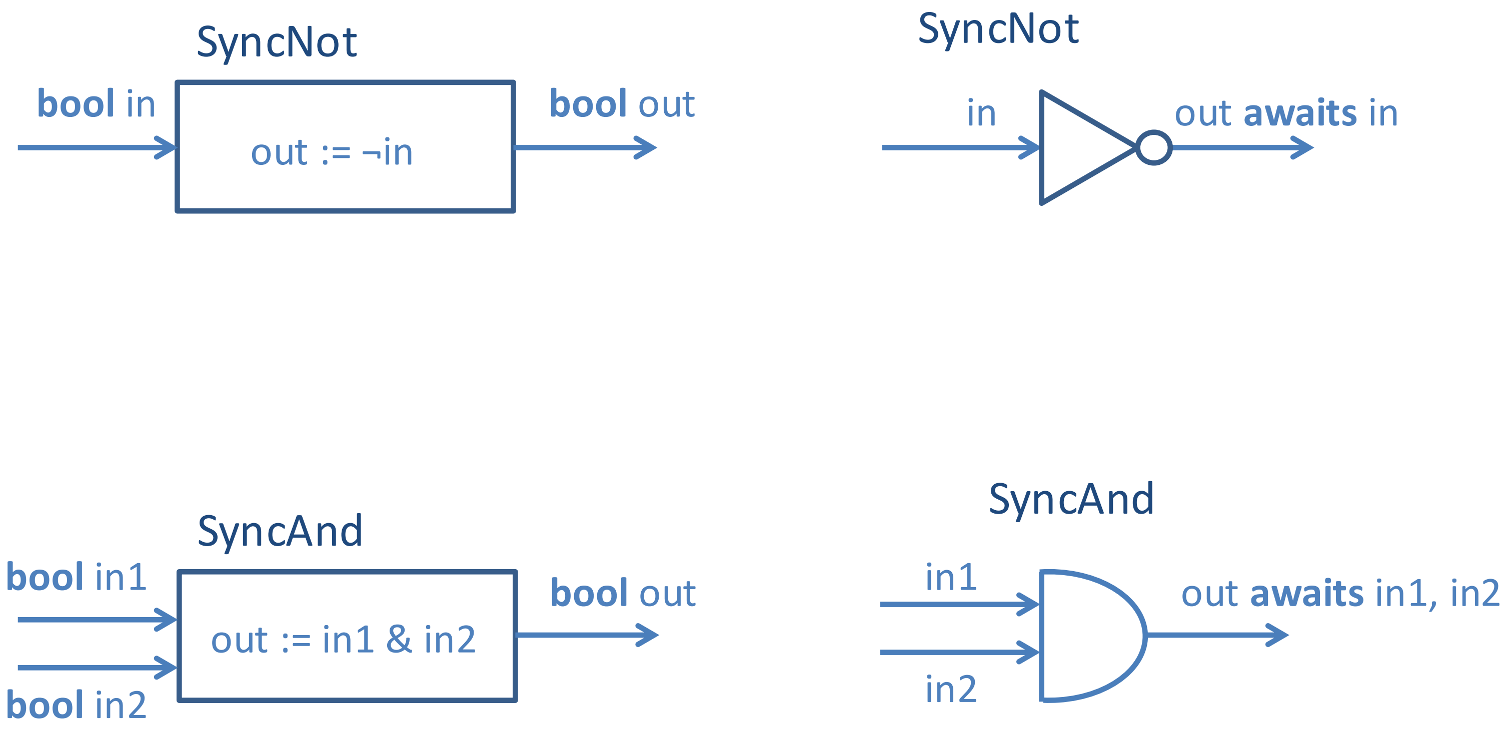
Component (de)composition can be stratified

Bottom-Up Design

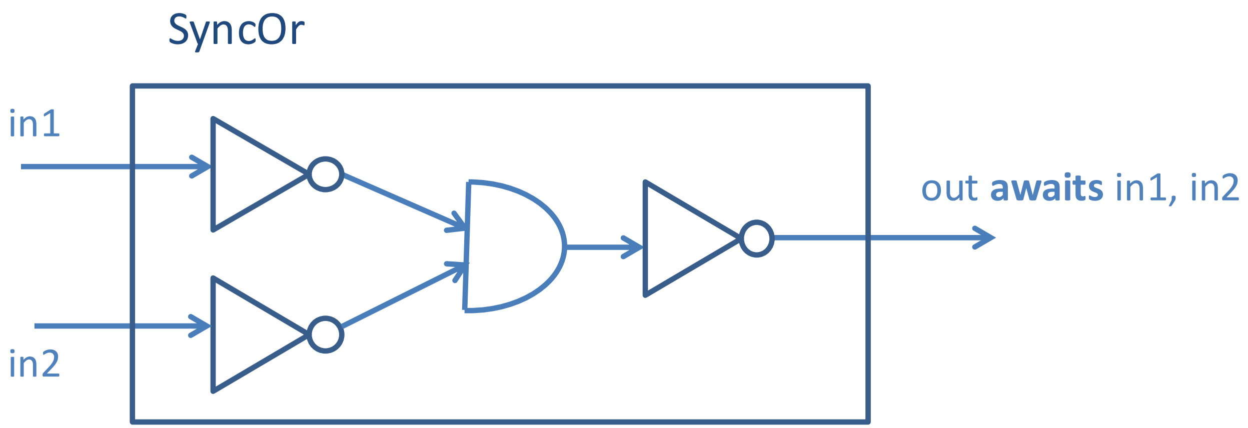
- Design basic components
- Compose existing components in block-diagrams to build new components
- Maintain a library of components, and try to reuse at every step

Canonical example: Synchronous circuits

Combinational Circuits

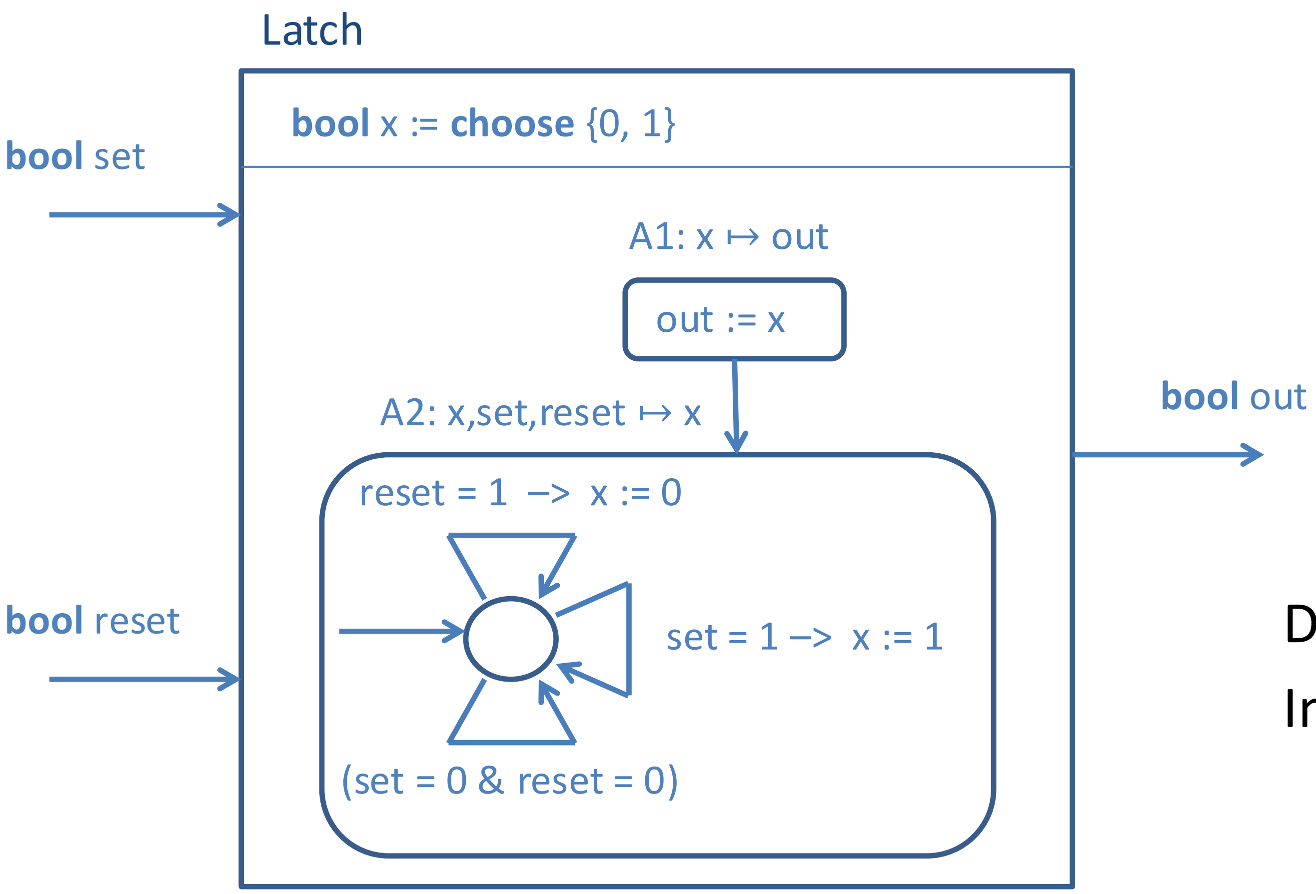


Design OR gate



Recall: $A \vee B \equiv \neg(\neg A \wedge \neg B)$

Synchronous Latch



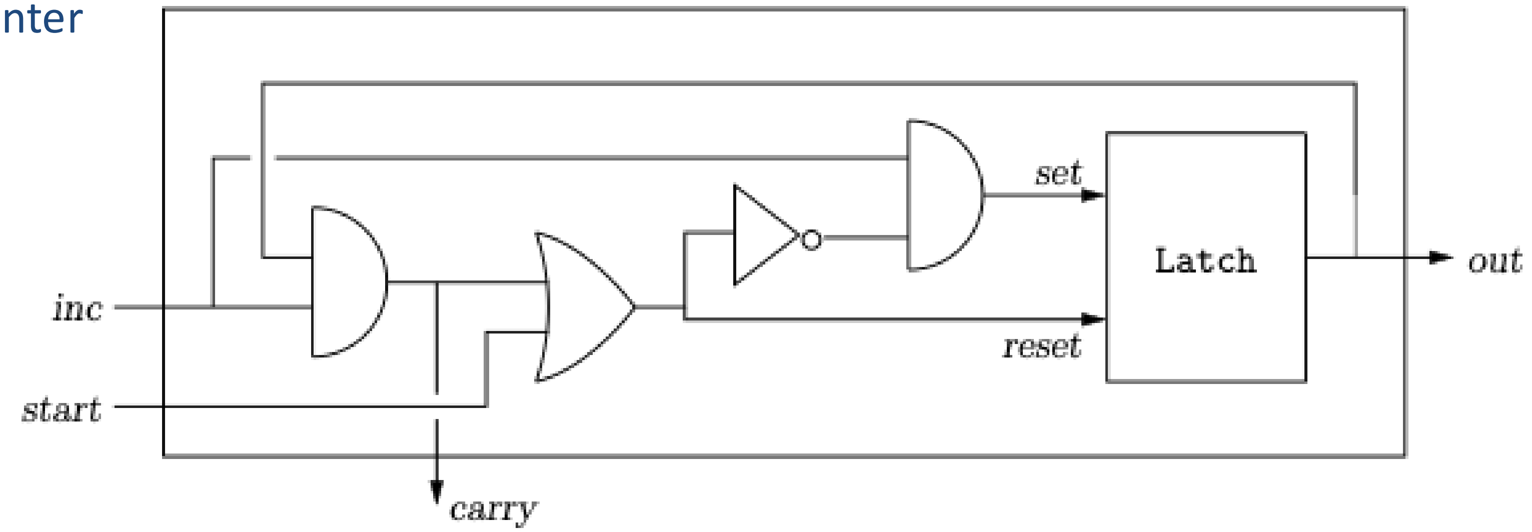
Deterministic?

Input-enabled?

Stores a single bit of information and holds it until it is updated by new input signals

Designing Counter Circuit (1)

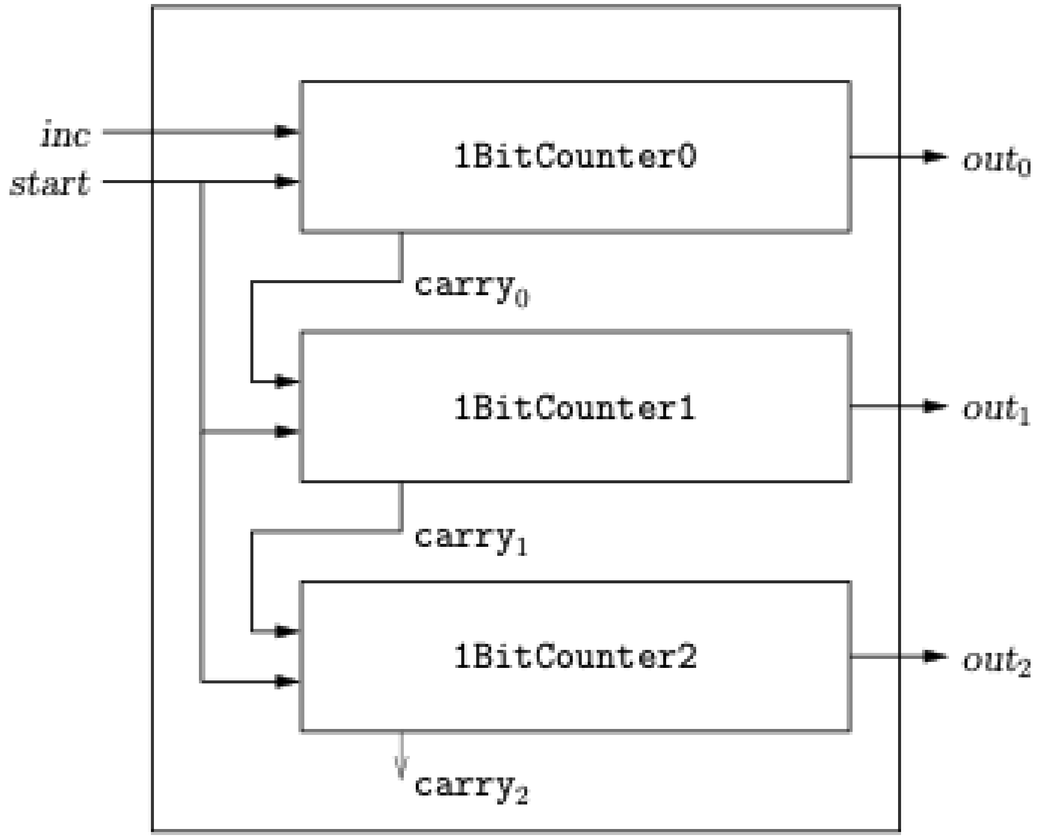
1BitCounter



Are await-dependencies acyclic?

Designing Counter Circuit (2)

3BitCounter

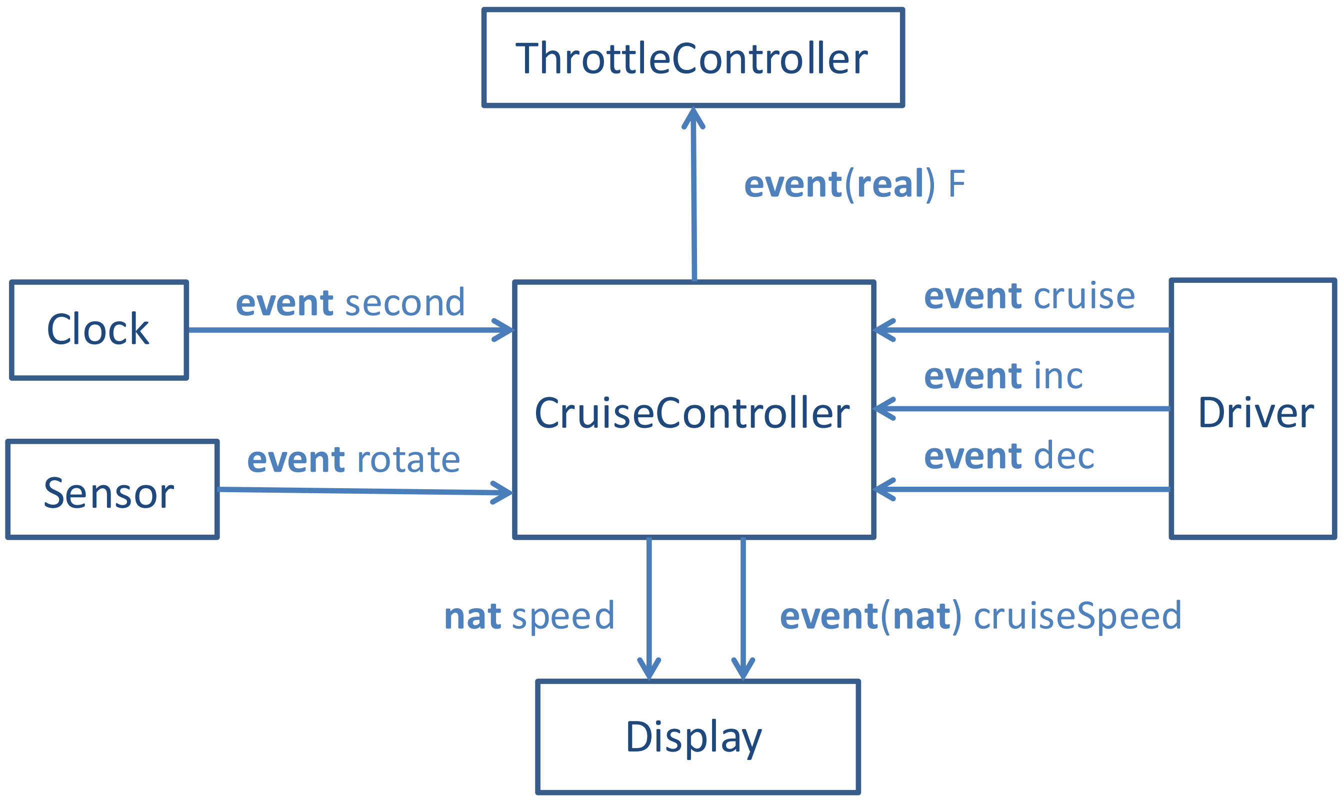


Top-Down Design

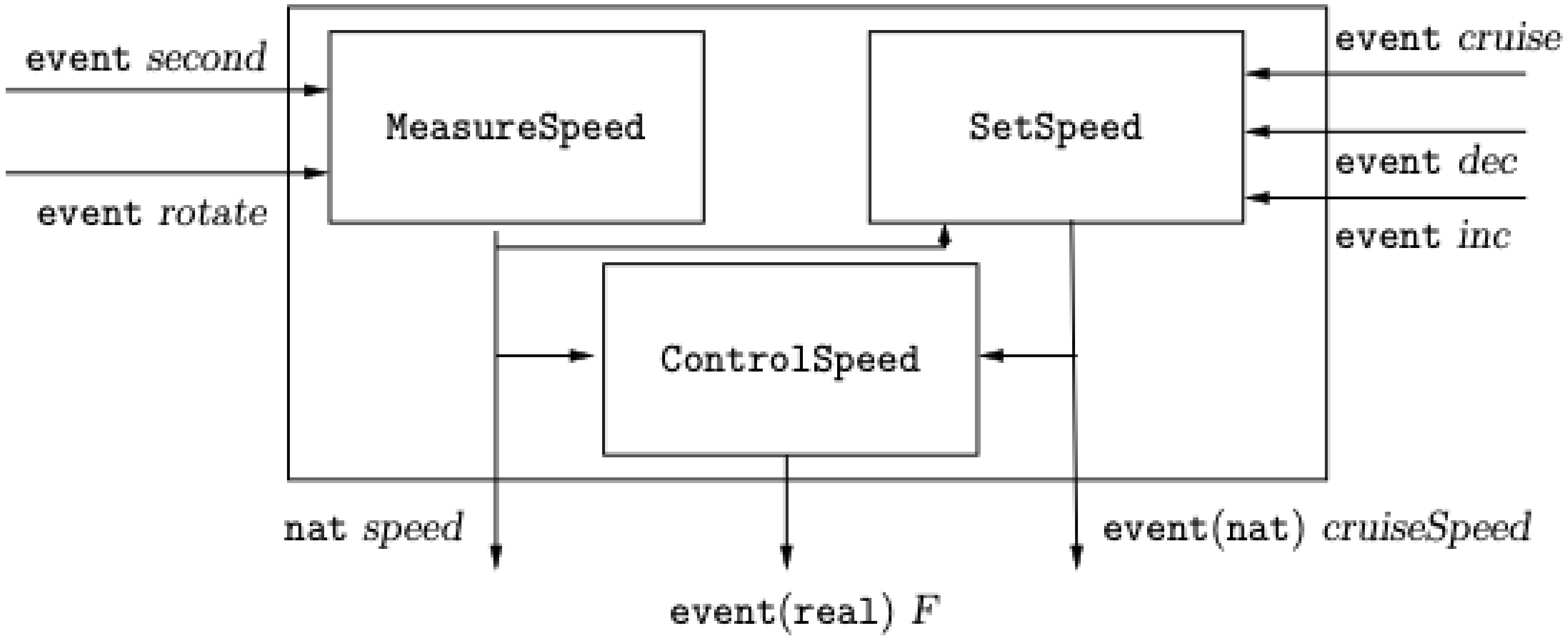
- **Starting point:** Inputs and outputs of desired system C
- Models/assumptions about the environment C operates in
- Informal/formal description of C's desired behavior

Example: Cruise Controller

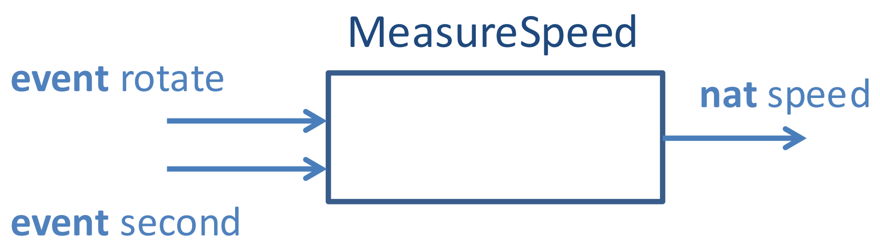
Top-Down Design of a Cruise Controller



Decomposing CruiseController



Tracking Speed

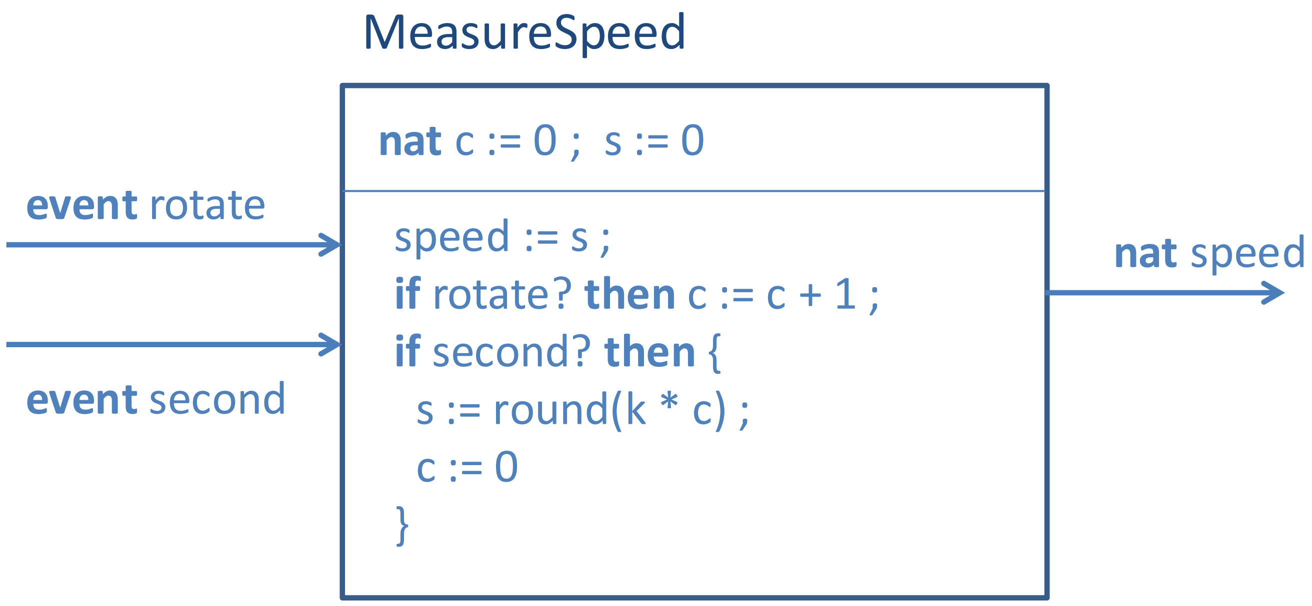


Inputs: Events rotate and second

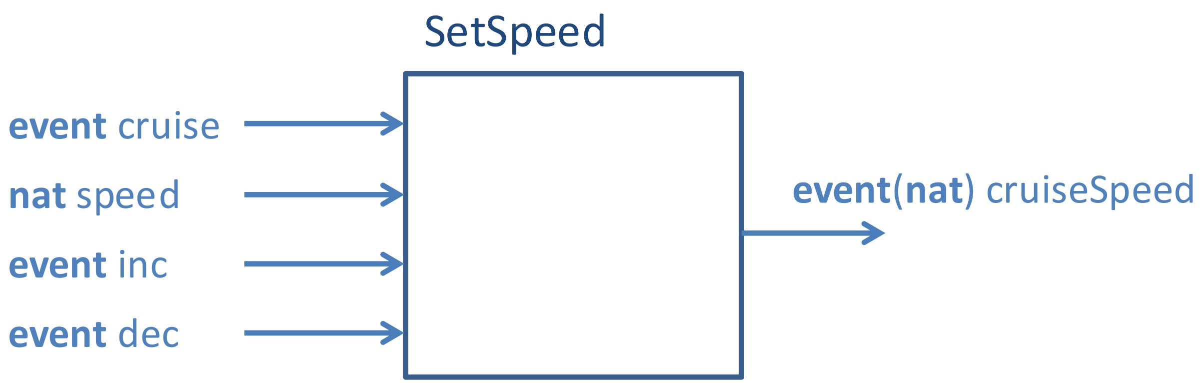
Output: current speed

Behavior: Computes the number of rotate events per second

Tracking Speed



Tracking Cruise Settings



Inputs from driver: commands to turn the cruise-control on/off and increment/decrement desired cruising speed from driver

Input from MeasureSpeed**:** current speed

Output: desired cruising speed

What assumptions can we make about simultaneity of events?

Should we include safety checks to keep desired speed within bounds?

Tracking Cruise Settings

event cruise
nat speed
event inc
event dec

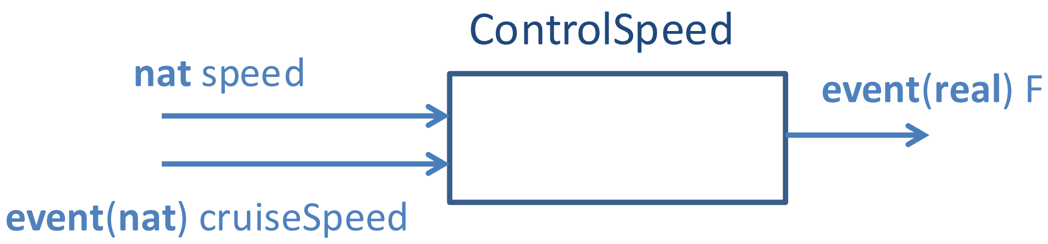
SetSpeed

```
nat s := minSpeed ;  bool on := 0

if cruise? then {
  on := ¬on ;
  if speed < minSpeed then s := minSpeed
  else if speed > maxSpeed then s := maxSpeed
  else s := speed
}
else if dec? & on & s > minSpeed then s := s - 1
else if inc? & on & s < maxSpeed then s := s + 1 ;
if on then cruiseSpeed ! s
```

event(nat) cruiseSpeed

Controlling Speed



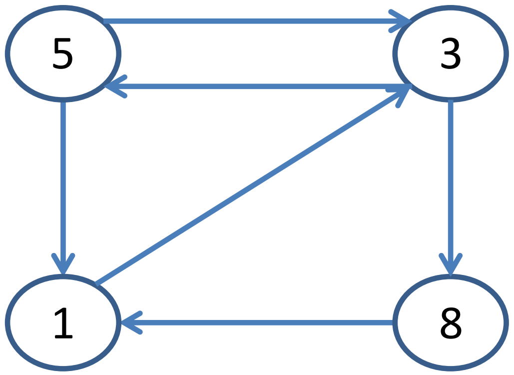
Inputs: Actual speed and desired speed

Output: Pressure on the throttle

Goal: Make actual speed equal to the desired speed
while maintaining key physical properties such as stability

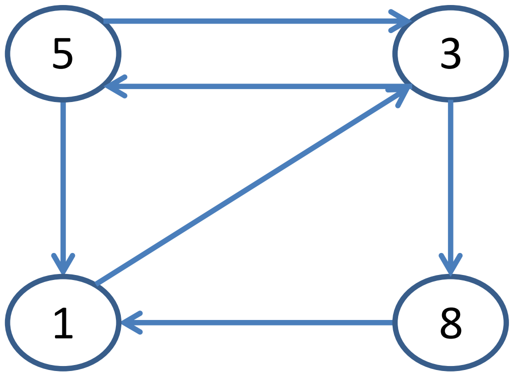
Design relies on theory of dynamical systems (Chapter 6)

Synchronous Networks



- Time divided into slots, with all nodes synchronized
- In one round, each node can get a message from each neighbor
- Design abstraction for simplicity
- Some implementation platforms directly support such a *time-triggered* network: WirelessHART (control), CAN (automotive)

Modeling Synchronous Networks



Assumption: Each link is directed and connects two nodes

Alternative: Broadcast communication (everyone can listen)

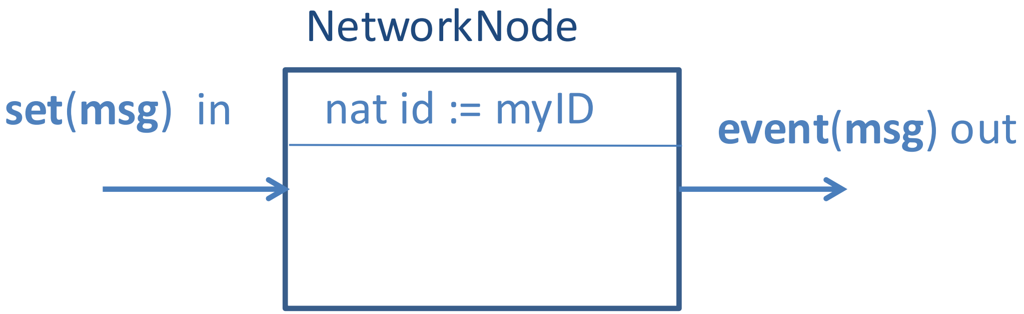
Assumption : Communication is reliable

Alternative: Messages may be lost, collisions in broadcast

Network is a directed graph

Each link can carry one message in each time slot

Component for a Network Node



Nodes do not know network topology

- Do not know which nodes they are connected to

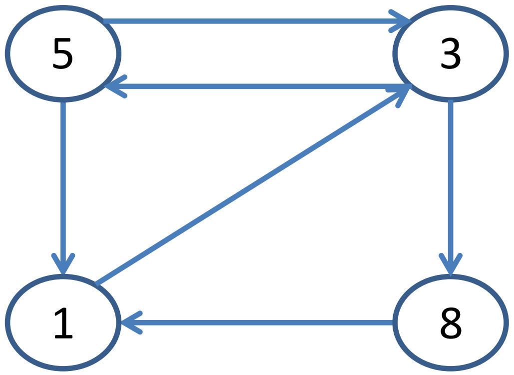
Each node has unique identifier, myID

- Useful for network identification problems

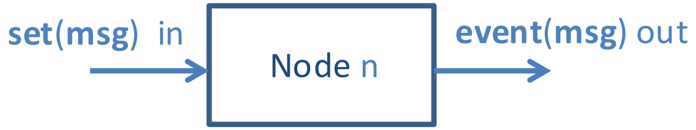
Interface for each node:

- **Input:** a set of **msg** (delivered by the network)
- **Output:** an event carrying **msg** (may be absent in some rounds)
- Output should not await input

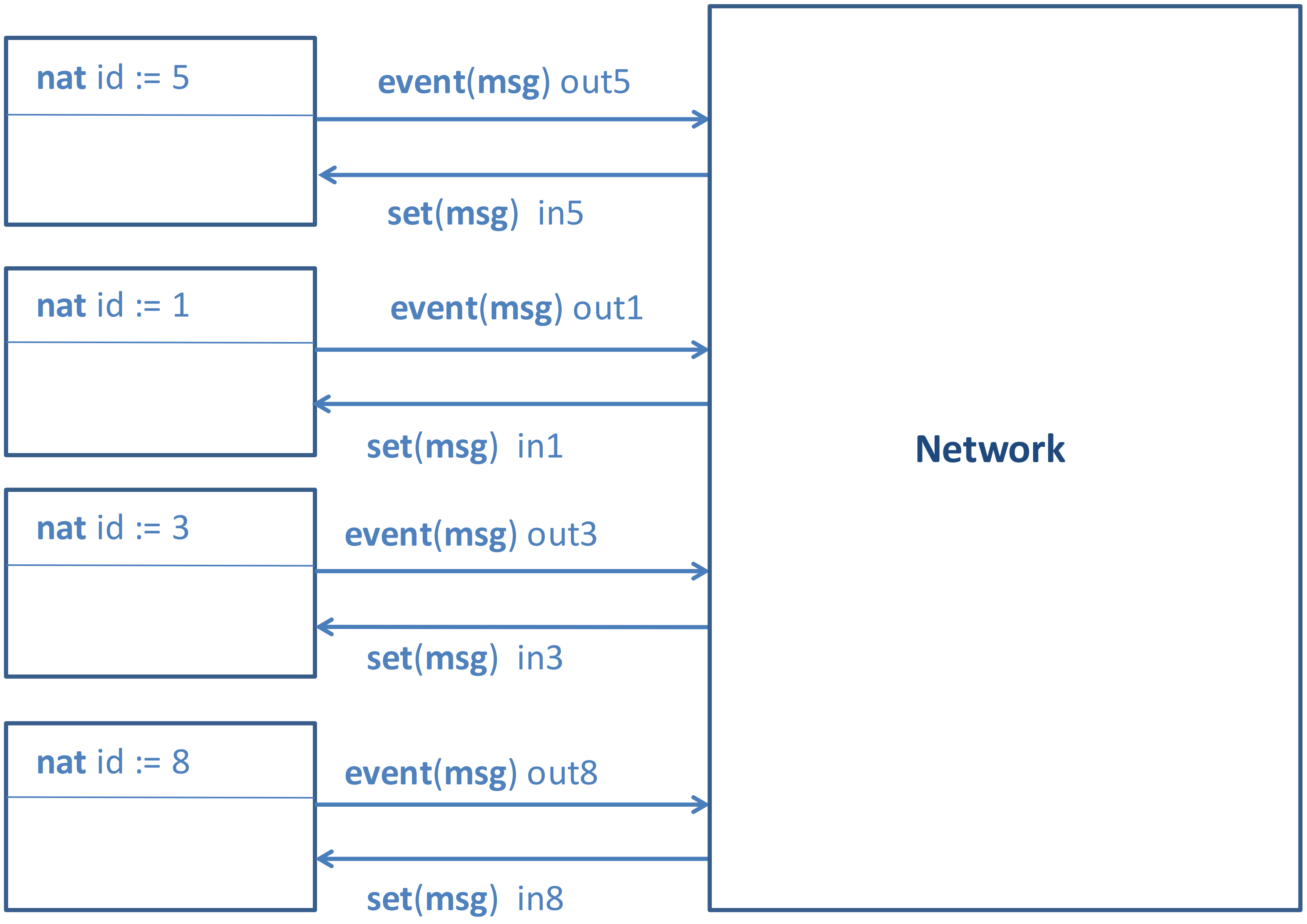
Modeling Synchronous Networks



- The description of each node is independent from the network
- The network itself is modeled as a synchronous component
- The network description depends on the network graph
  - **Input variables:** for each node n, in_n of type **set**(**msg**)
  - **Output variables:** for each node n, out_n of type **event**(**msg**)



- Network is a combinational component
  (simply routes messages)


nat id := 5
event(msg) out5
set(msg) in5
nat id := 1
event(msg) out1
set(msg) in1
nat id := 3
event(msg) out3
set(msg) in3
nat id := 8
event(msg) out8
set(msg) in8
Network

Network

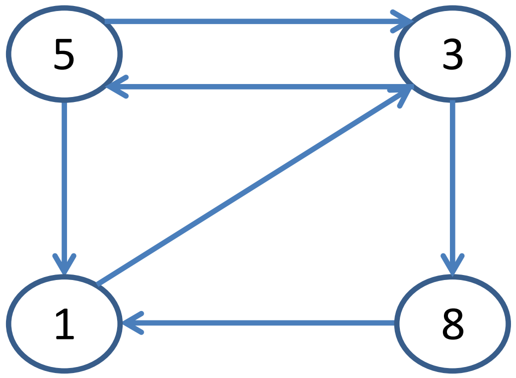
- Value of in1 should equal the set of messages sent on links incoming to node 1
- Sample code:

  in1 := EmptySet ;

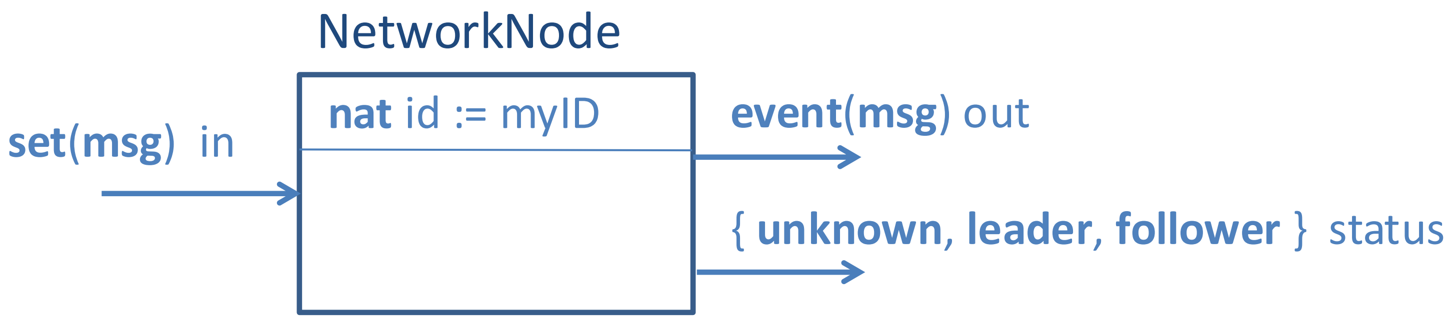
  if out5? **then** Insert(out5, in1) ;

  if out8? **then** Insert(out8, in1) ;

- Update of in5, in3, in8 is similar



Leader Election Protocol



Classical coordination problem: Elect a unique node as a leader

- Exchange messages to find out which nodes are in network
- Output the decision using the variable status

Requirements:

1. Eventually every node sets status to either leader or follower
2. Only one node sets its status to leader

Leader Election: Flooding Algorithm

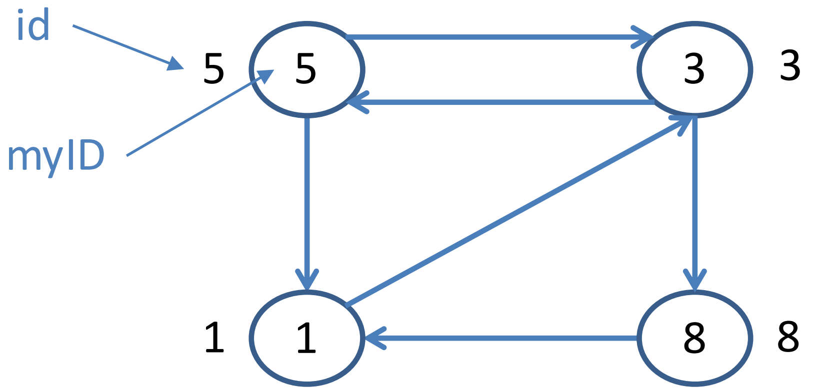
Goal: Elect the node with highest identifier as the leader

Strategy: Transmit to your neighbors the highest id you have encountered so far

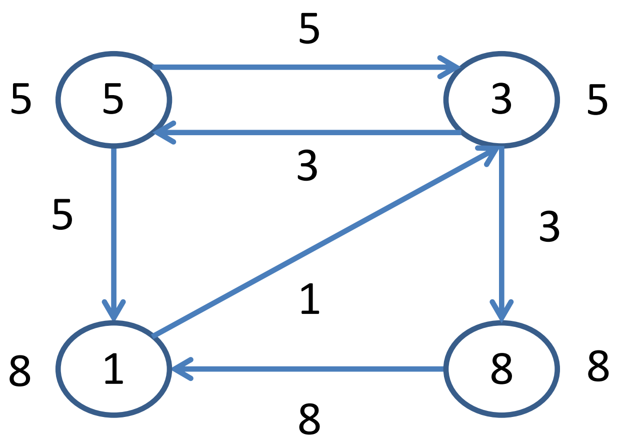
Implementation:

- Maintain a state variable, id, initialized to your own identifier myID
- In each round,
    1. transmit value of id on output
    2. receive input values from the network
    3. if a value higher than id received, then update id

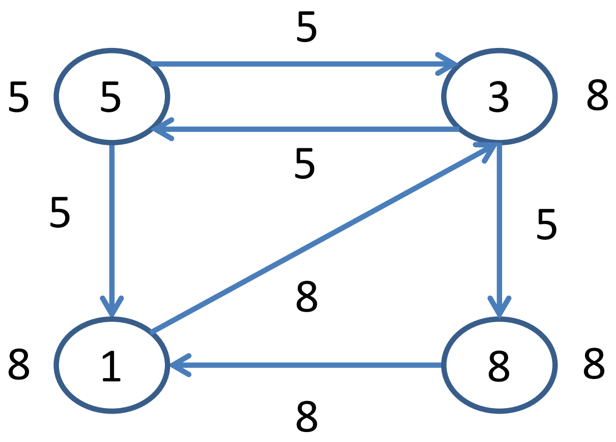
Execution of Leader Election



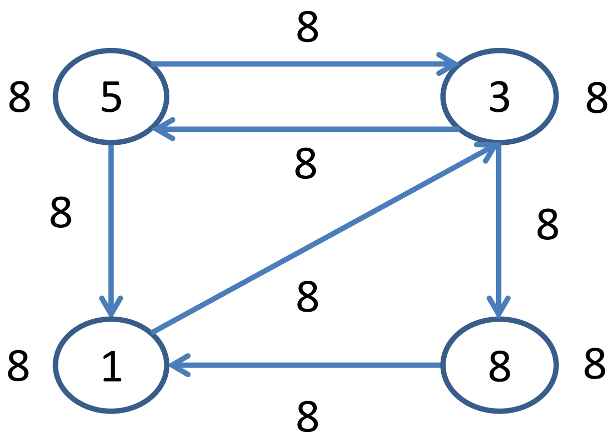
Initially



First round



Second round

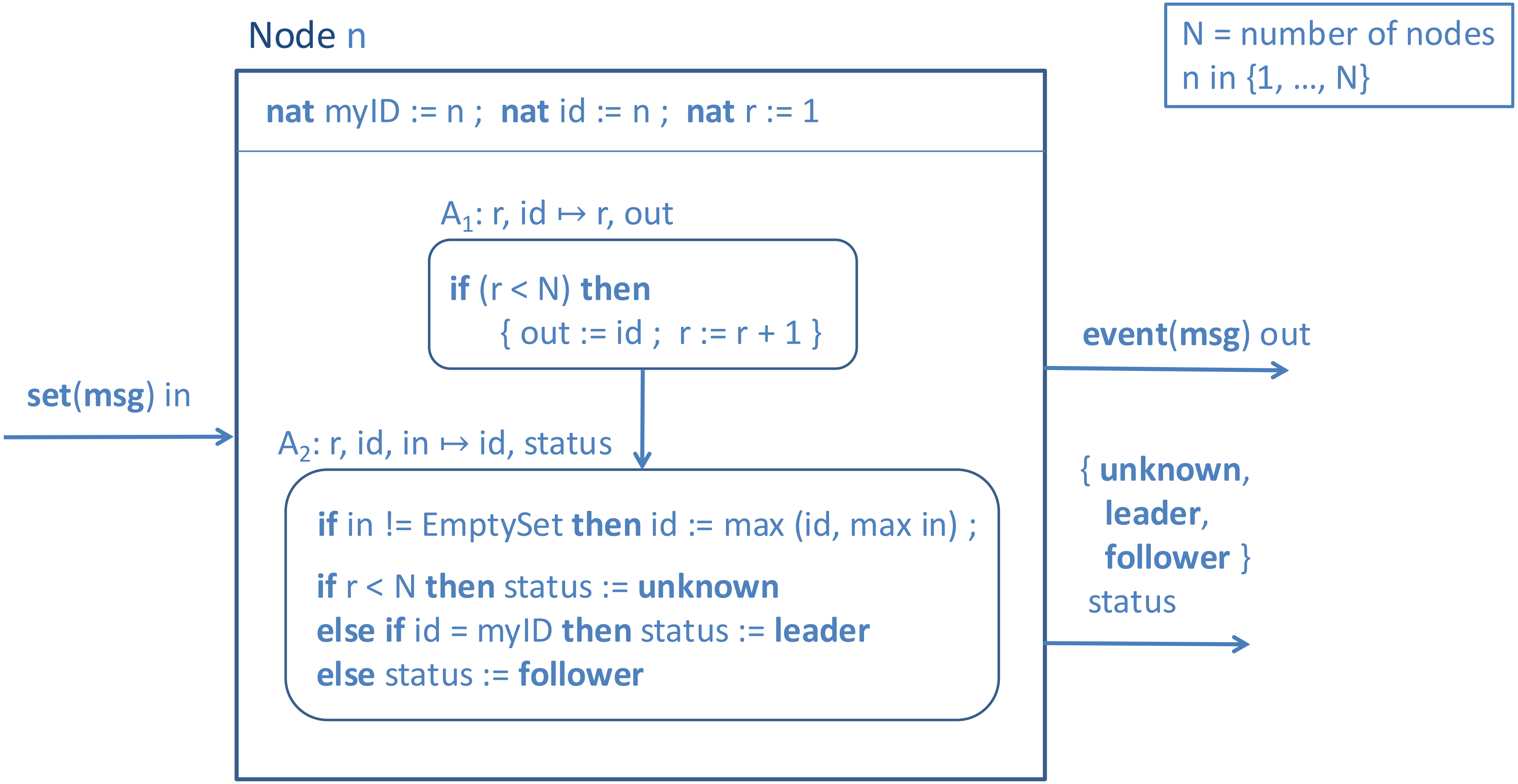


Third round

Leader Election

- When should a node stop and make a decision?
  - When it knows that enough rounds have elapsed for message from every node to reach every other node
- Correctness depends on following assumptions:
  1. Network is *strongly connected*: for all nodes m and n, there is a directed path from m to node n
  2. All nodes know an upper bound N on total number of nodes
- Implementation of decision rule:
  - Maintain a state variable r to count rounds, initially 1
  - In each round, r is incremented
  - When r = N, decide
- What should the decision be?

Node Component for Leader Election



Leader Election

General questions:

- Does a node really have to wait for N rounds?
- If a node receives a value higher than its own identifier, can it stop participating (i.e. transmit no more messages)?
- Does a node have to transmit in each round?
  When can it choose to skip a round without affecting correctness?

Credits

Notes based on Chapter 2 of

Principles of Cyber-Physical Systems
by Rajeev Alur
MIT Press, 2015