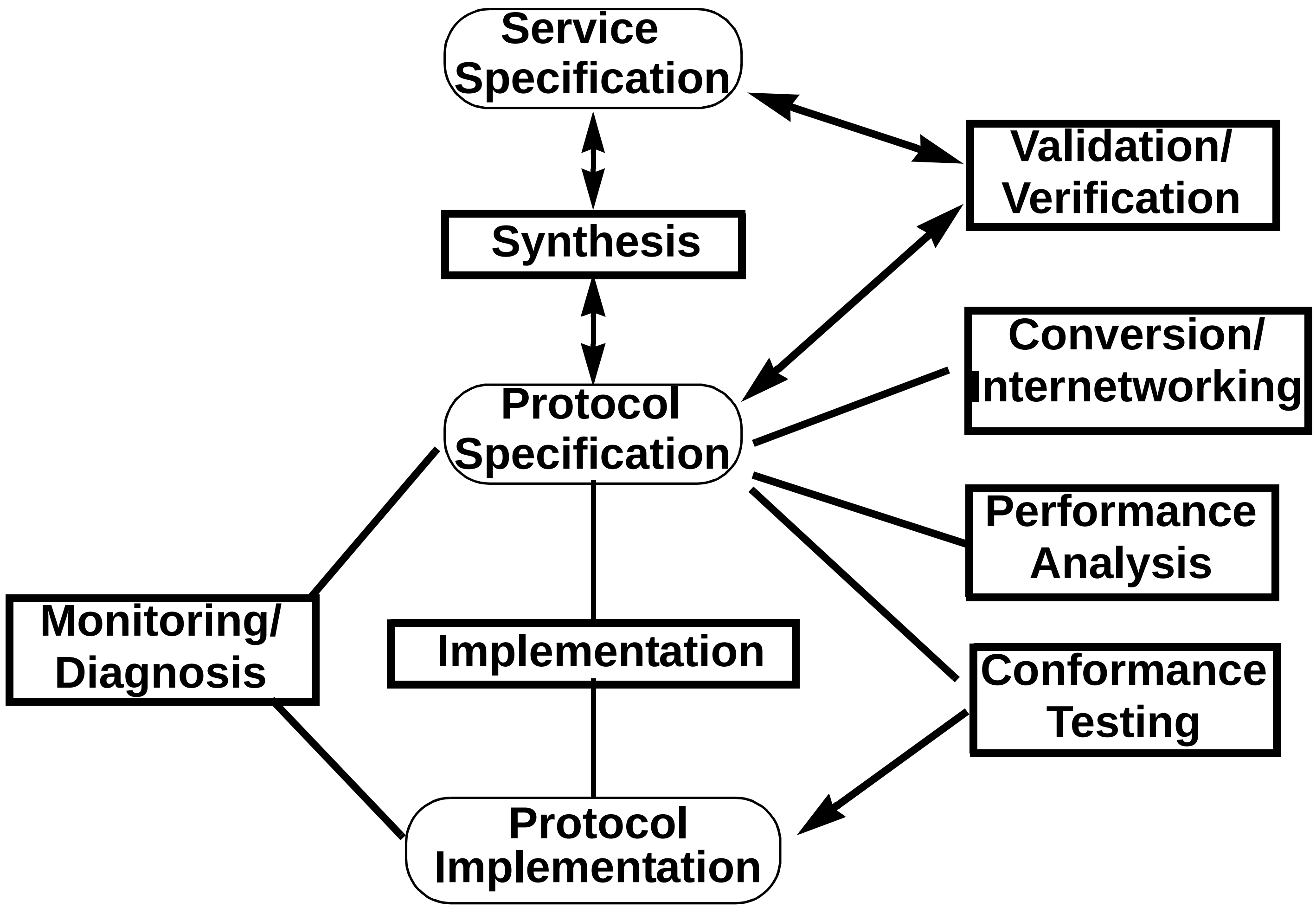
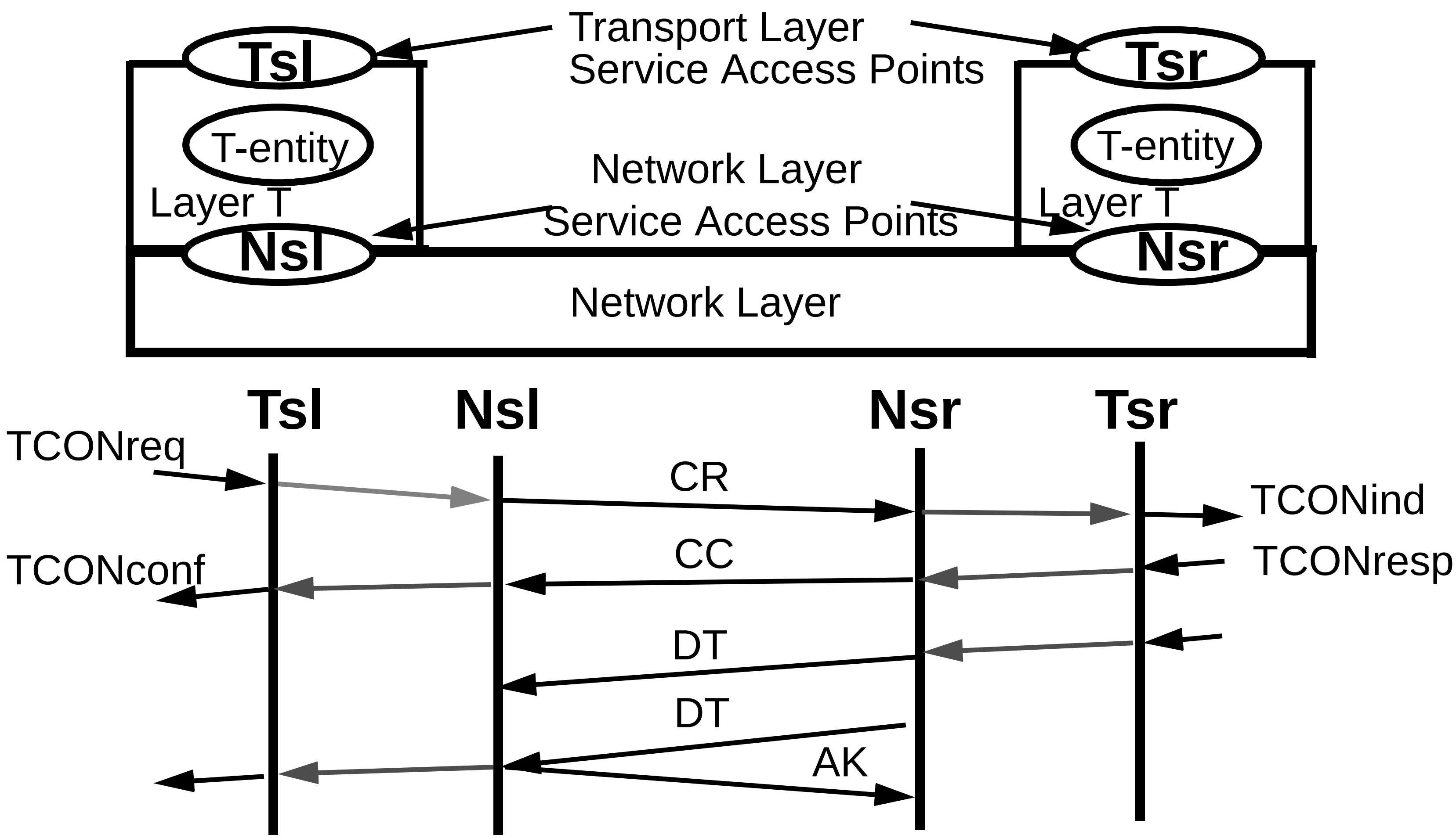
Protocol Engineering



- Service specification is the document that describes how a protocol layer provides network services to its users or protocol modules in the upper layers
- Protocol specification is the documentation that describes the message format and exchange sequences among the protocol modules of the layer, which realizes the service specification.
- Protocol Synthesis is the process that takes the service specification and generates the error-free protocol specification, or combines multiple protocol specifcations (phases) into an error free protocol specification.
- Protocol Implementation is the process that takes the protocol specification and develops the protocol software modules.
- Protocol Validation/Verification is the process that verifies if the protocol specification actually realizes the service specification. Validation sometimes refers to check the protocol specification will not get into deadlock, unspecified reception, and livelock errors.
- Conformance testing is the process that given a protocol specification, generate the short test suite for testing the protocol implemenation (software modules).

Protocol Specification using Sequence Chart or Message Flow Diagram



Apply Formal Method To Protocol Specification

- The sequence chart is good at capturing the normal/specific scenario of system interactions. It is difficult to show several/all possible scenarios simultaneously on a chart and that often leads to ambiguity in the specification.

The use of Formal Method

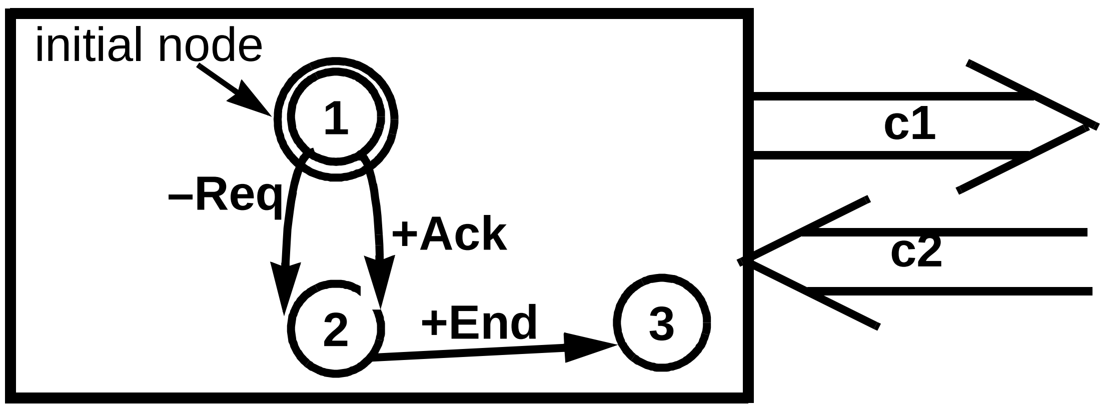
- Provide a formal and unambiguous way of designing and documenting protocols.
- Allow formal analysis (verification/validation/performance analysis) before protocols are implemented.
- Allow automatic and direct generation of executable programs from the formal specification.

Specification Languages

- Informal methods -- such as the sequence chart
- Formal methods
  State Transition Models
  —Finite State Machines (FSM),
  —Communicating FSM (CSFM),
  —Petri nets
  Programming Languages Models
  —Abstract Programs
  —CCS (Calculus of Communicating systems), CSP
  —Temporal logic
  Hybrid Models
  —Extended FSM (EFSM)
- Language Standards
  —SDL (FSM + extensions)
  —Estelle (EFSM + extended Pascal)
  —LOTOS (CCS+ADT)

Communicating Finite State Machines (CFSM)

- Protocol is described as a set of Communicating Finite State Machines.
- Each CFSM represents a component (or process) of the network (in OSI term, a protocol entity, e.g. sender, receiver).
- Each CFSM is represented by a directed labelled graph where
  —Nodes represent states (conditions) of the process;
  —Edges represent transitions (events) of the process.



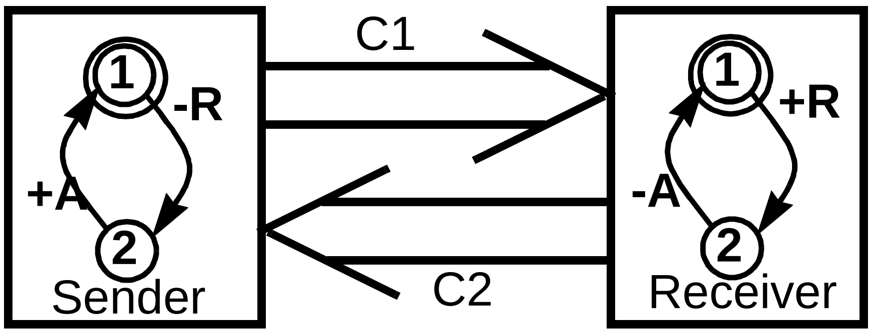
- Transitions include actions taken the process (e.g. the sending a message) or external stimuli (e.g. the reception of a message).
- The sending message transition is labelled as –Msg where Msg is the type of messages being sent. The receiving message transition is labelled as +Msg where Msg is the head message on the incoming FIFO queue of the CFSM.

CFSM operating semantic

- The channels that connect CFSM's are assumed to be FIFO queues.
  An error-prone channel is modelled as a CFSM.
- Initial node—starting state of a CFSM.
  Final node—no transition.
  Receiving node—all (outgoing) transitions are receiving transitions. If no message or incorrect msg in the channel, the node will be blocked.
  Sending node—all transitions are sending transitions. They are not blocked.
  Mix node—has both receiving and sending transition.
- Starting at the initial node, a CFSM traverses the nodes and transitions.
  The node currently being visited is called the current node.
- When a machine traverses a sending transition, it sends/appends a message with the same label to its outgoing channel.
- A machine at a node cannot traverse its receiving transition unless there is a message matched with the same label on the head of its incoming channel.
- When a machine traverses a receiving transition, it removes the matched head message of its incoming channel.
- Among several possible transitions, a machine traverses one non-deterministically

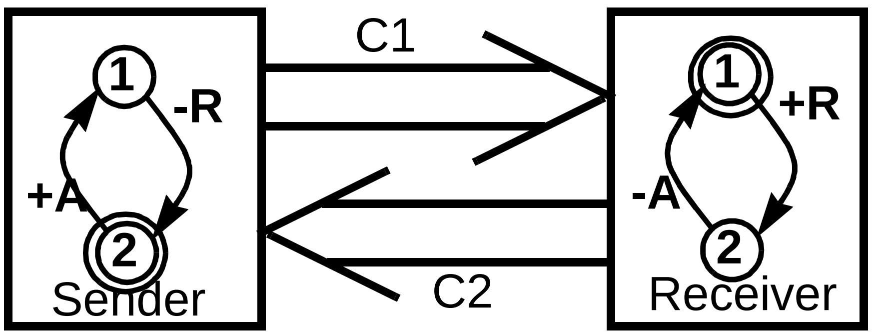
Networks of CFSMs

- Example 1: Simple request-response protocol.



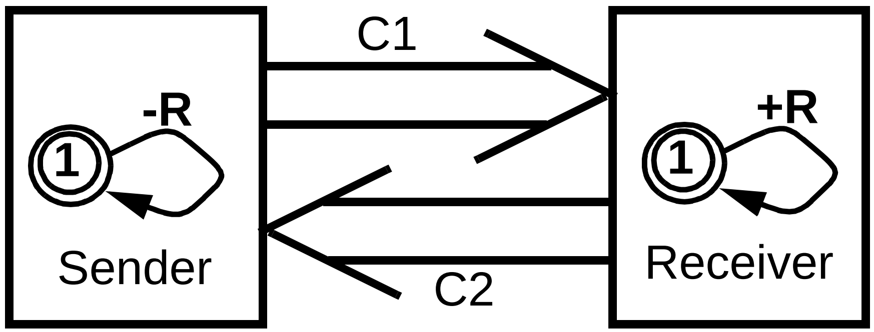
R: request
A: Acknowledgment

- Example 2: What happens if we change the initial node of a CFSM?



R: request
A: Acknowledgment

- Example 3: An aggressive protocol with a self-sending loop.



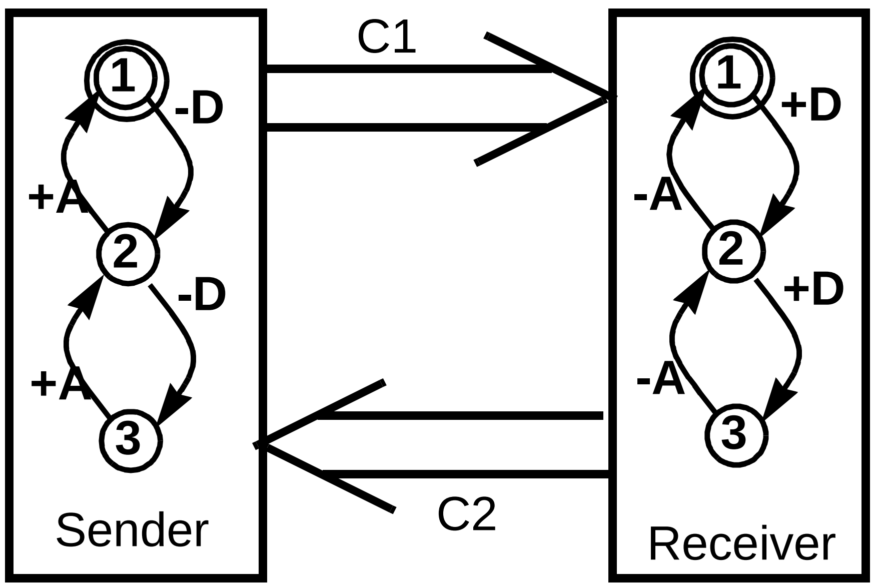
D: Data

What happens to C1?

Do we need C2?

What happens to a slow receiver?

- Example 4: A simple sliding window protocol with a window size of 2.

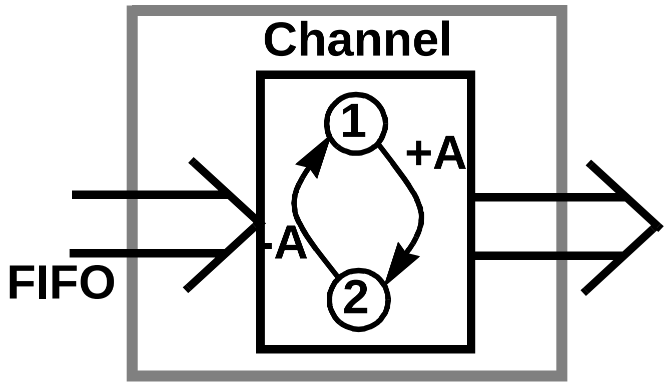


D: Data
A: Acknowledgment

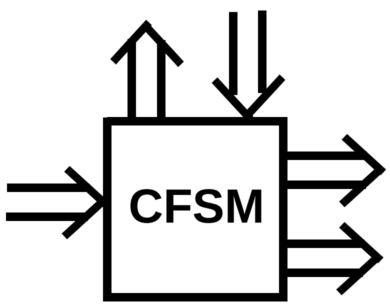
What if we distinguish the two data messages and the two acks?

CFSM Modeling Exercises

- How to specify the channel behavior as a CFSM which
  1) loses every other packet,
  2) loses packets sometimes,
  3) loses and corrupts the packet sometimes?

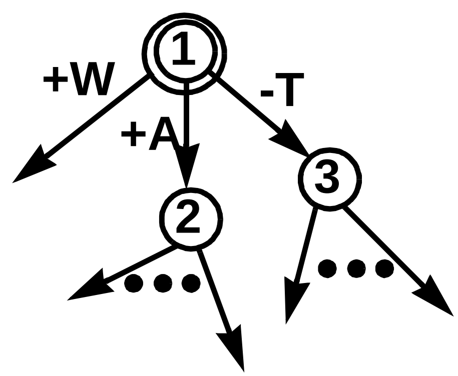


- How to extend the model to specify CFSMs with the multiple channels?



Pros and Cons of the CFSM model

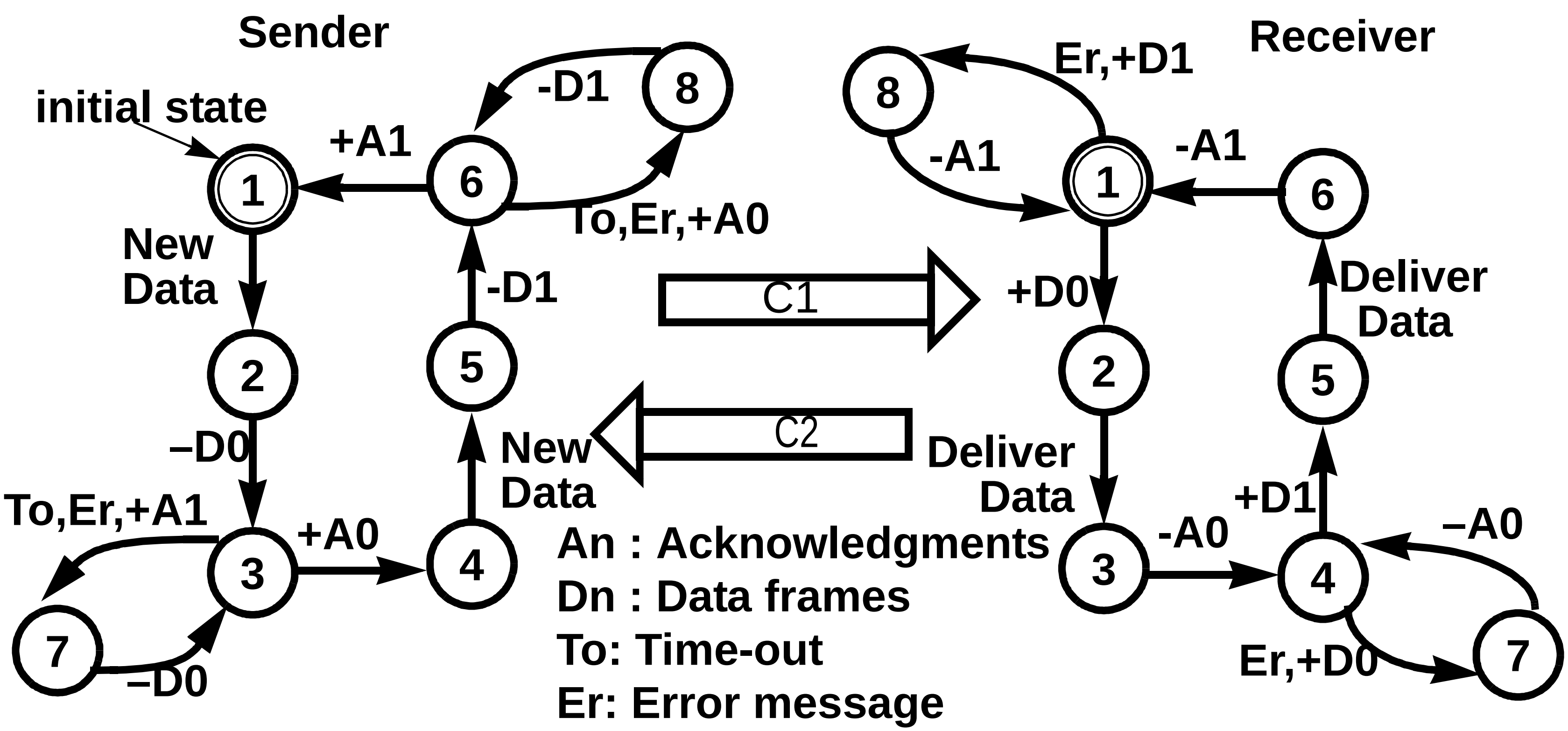
- CFSM deals only with the state-transition aspect of protocols; it does not address the data aspect of protocols, e.g., message content or format.
- It can not handle protocols where state variables have a wide range of values. Extended FSM were proposed but EFSM becomes difficult to analyze.
- The FIFO channels assumption in CFSM is very powerful, just think about how to model an unbounded or even a large buffer using Petri net.
- CFSM is an abstract model. The non-determinism in the execution of transitions of a mix node may result in different implementation. You can



always expand the specification, e.g., replacing node 1 with a subgraph.

The Alternating Bit Protocol as CFSMs

The Alternating Bit Protocol is used to guarantee the correct data delivery between a sender and receiver connected by an error channel that loses or corrupts messages. It got the name since it uses only one additional control bit in the message and this control bit only alternates when the previous message is correctly received.....(Transition with three lables are short hand for 3 transitions)



Verifying the Alternating Bit Protocol

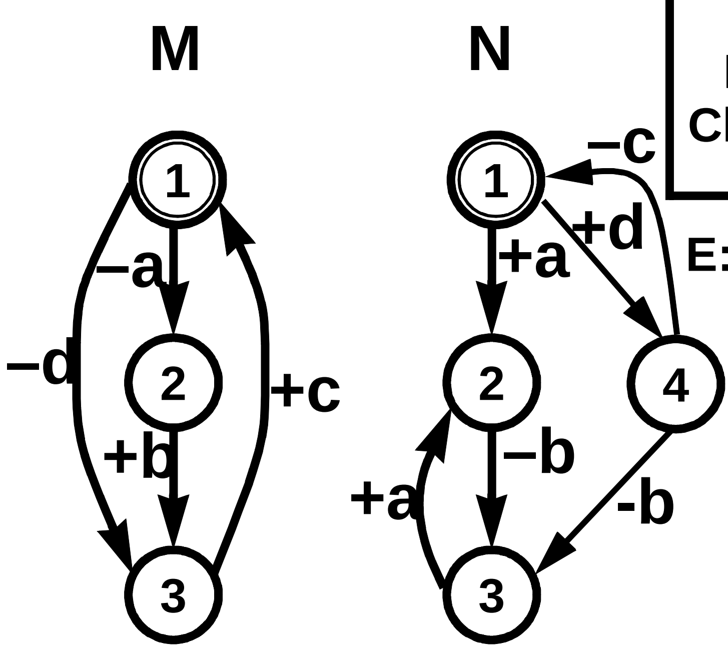
Assume that C1 is the outgoing channel of the sender and C2 is the outgoing channel of the receiver. Let us assume that C1 loses the odd numbered messages, i.e., the 1st, 3rd, 5th, and so on, while C2 delivers every message.
Let S be the sender, R be the receiver, and E stands for an empty channel.
Let the 4-tuple (sender state, receiver state, C1 content, C2 content) represent the global state, a snapshot of the overall system state.
The following state transition sequence illustrates that the alternating bit protocol in page 8 is capable of delivering data without duplication and in the right order.

(1,1,E,E)--S:NewData-->(2,1,E,E) sender receives data, x, from its upper layer
(2,1,E,E)--S:-D0-->(3,1,D0,E) sender attaches a sequence bit 0 after x. D=x
(3,1,D0,E)--C1:lose D0-->(3,1,E,E)
(3,1,E,E)--S:To-->(7,1,E,E)
(7,1,E,E)--S:-D0-->(3,1,D0,E) retransmit D0
(3,1,D0,E)--R:+D0-->(3,2,E,E) This time C1 correctly delivers the message.
(3,2,E,E)--R:DeliverDate-->(3,3,E,E) receiver delivers x to its upper layer
(3,3,E,E)--R:-A0-->(3,4,E,A0)
(3,4,E,A0)--S:+A0-->(4,4,E,E)
(4,4,E,E)--S:NewData-->(5,4,E,E) sender receives data, y, from its upper layer
(5,4,E,E)--S:-D1-->(6,4,D1,E) sender attaches a sequence bit 1 after y. D=y
(6,4,D1,E)--C1:lose D1-->(6,4,E,E) this is the third message received by C1
(6,4,E,E)--S:To-->(8,4,E,E)
(8,4,E,E)--S:-D1-->(6,4,D1,E) retransmit D1
(6,4,D1,E)--R:+D1-->(6,5,E,E) This is the fourth msg. C1 delivers it.
(6,5,E,E)--R:DeliverData-->(6,6,E,E) receiver delivers y to its upper layer
(6,6,E,E)--R:-A1-->(6,1,E,A1)
(6,1,E,A1)--S:+A1-->(1,1,E,E)

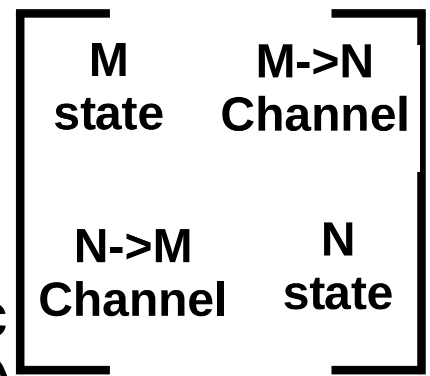
Note that the message sequence xy from the upper layer of the sender is correctly delivered to the upper layer of the receiver.

Protocol Verification using Reachability Analysis

Protocol Specification

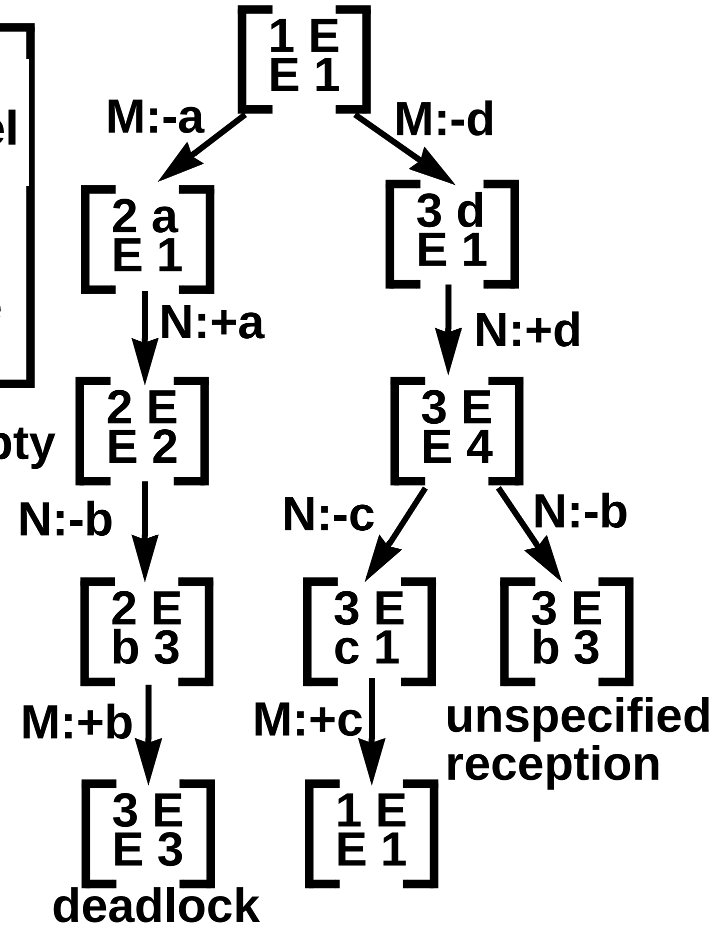


Global State
=



E: Channel Empty

Reachability Graph(Tree)



Reachability Analysis

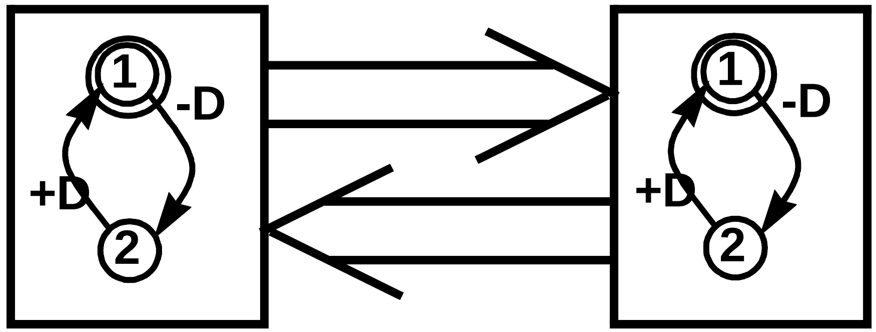
- It is a global state exploration process that starts from the initial global state and recursively explores all the possible transitions that lead to new global states. The result is a reachability graph, which captures all possible states.

Protocol Design Errors

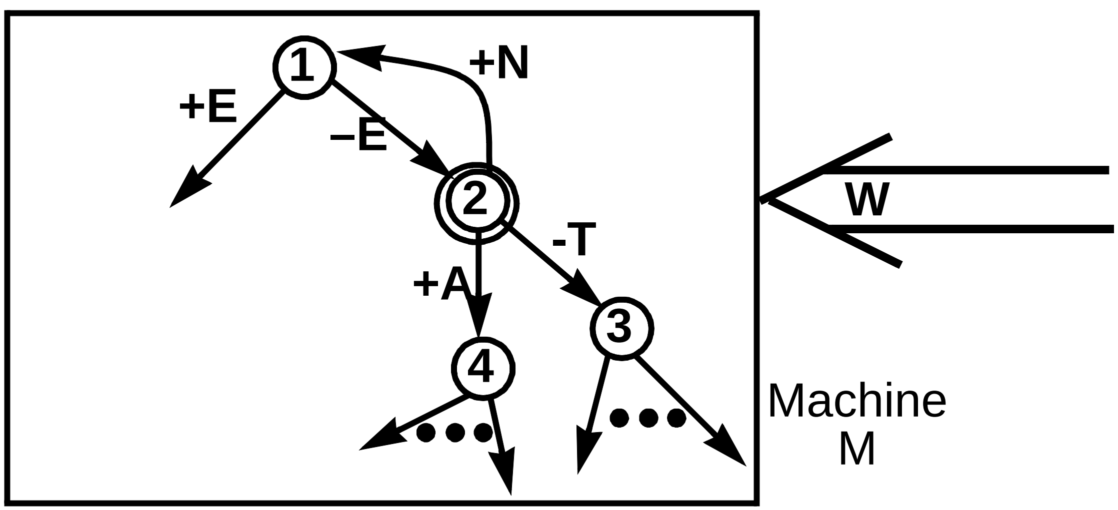
- Unspecified reception—at receiving/final nodes, head msg ¦ transition labels. What happens if you throw away those head msgs that are not specified?
- Deadlock—both at receiving nodes, no msg in channels.
- Livelock=processes keep exchanging messages but not making “effective progress”.
  need to mark transitions as either effective-progress or non-effective-progress and then check if there exist cycles in the reachability graph whose constituent transitions are all non-effective-progress.
- State ambiguity—global states with the same process states but different channel status. (This is a potential error, may not be a real one.)
- Channel buffer overflow. Give the simplest protocol example.
- Non-executable transitions—dead code. How do you detect that?

Protocol Verification Exercises

- What are the channel buffer sizes needed for the following two machines?

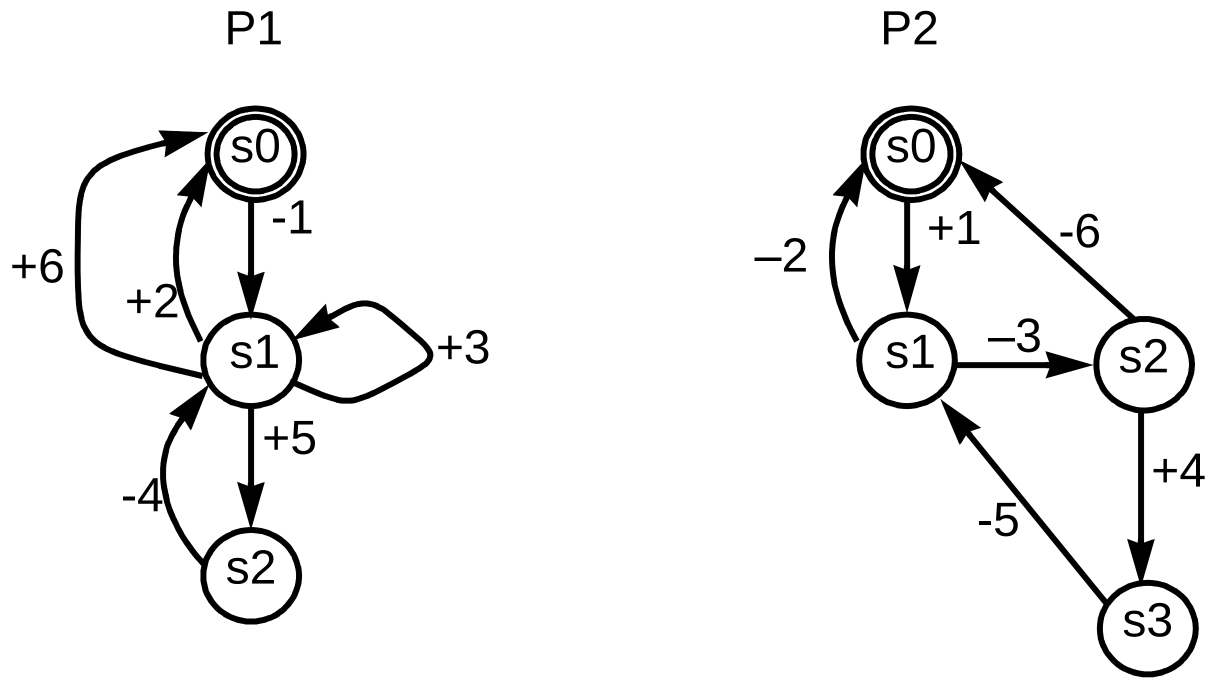


- Will the following situation considered to lead to an unspecified reception?



More Exercise on Reachability Analysis

- Find deadlock, unspecified reception global states in the following protocol



- There are also non-executable transitions and nodes in the two CFSMs.
- How many buffers are required in each of the two channel?
- I will give you the reachability graph and answer next time.

Pros and Cons of Reachability Analysis

Advantages:

- Easily automated.
- Many logical errors can be detected by only examining individual global states in the reachability graph.

Disadvantages:

- State space explosion problem.
- Does not work on unbounded protocols.
- Many relationships among the protocol state variables, expressing the desirable logical correctness properties of the protocol, are not apparent from simply traversing the reachability graph.

Tools for specification development

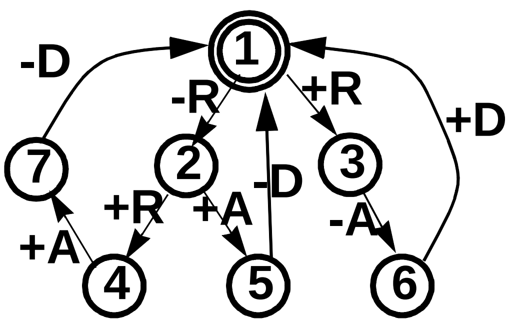
- CFSM--S-IBM-Zurich, *PROSPEC*
- Petri net--P-nut, PROTEAN
- SDL-- SDL-PR-GR, SDL-SDT
- EFSM--spanner
- Lotos--Sedos, Ottowa
- *Estelle*--NBS,Sedos,UBC

I have ported the state exploration tool of PROSPEC to X window system.
It is called setool.

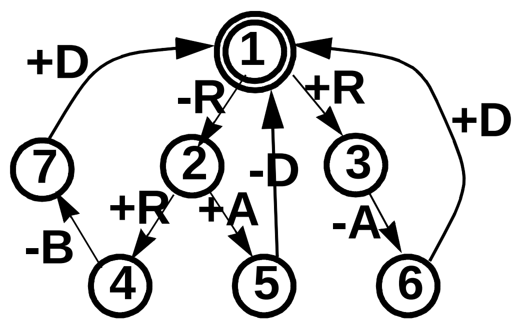
- To use the setool, include /users/server/students/cs522/bin in your **path** environment variable.
- The man page is in /users/server/students/cs522/tools/se/man/man1/setool.1 You can include /users/server/students/cs522/tools/se/man in your manpath
- There are some protocol examples in /users/server/students/cs522/tools/se/ examples.
- You can use the setool to verify your answers to the homework and exercises.

Exercise #2 **Solution at http://cs.uccs.edu/~cs522/pe/f2001hw2/hw2f2001sol.htm**

Exercise 1. Reachability Analysis. Given the following network of two communicating finite state machines,



Machine M



Machine N

a) Perform the reachability analysis on the Network (M, N).
b) What sizes of buffers are needed for the two FIFO channels?
c) Are there non-executable states or transitions?

Exercise 2. Describe the event sequence, starting from initial states, of the alternating bit protocol, if channel C2 loses the even messages, i.e., it loses the 2nd, 4th, 6th,... messages. Each event can be identified as starting global state--machine:transition->ending global state. For example, (1,1,E,E)--S:NewData-->(2,1,E,E) is the first event.

Include events up to the one that successfully delivers A1 to the Sender.