Local testing of MSC specifications

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Joint work with Puneet Bhateja

DNTTT '08, Cremona, Italy
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Extends joint work with Paul Gastin, K Narayan Kumar

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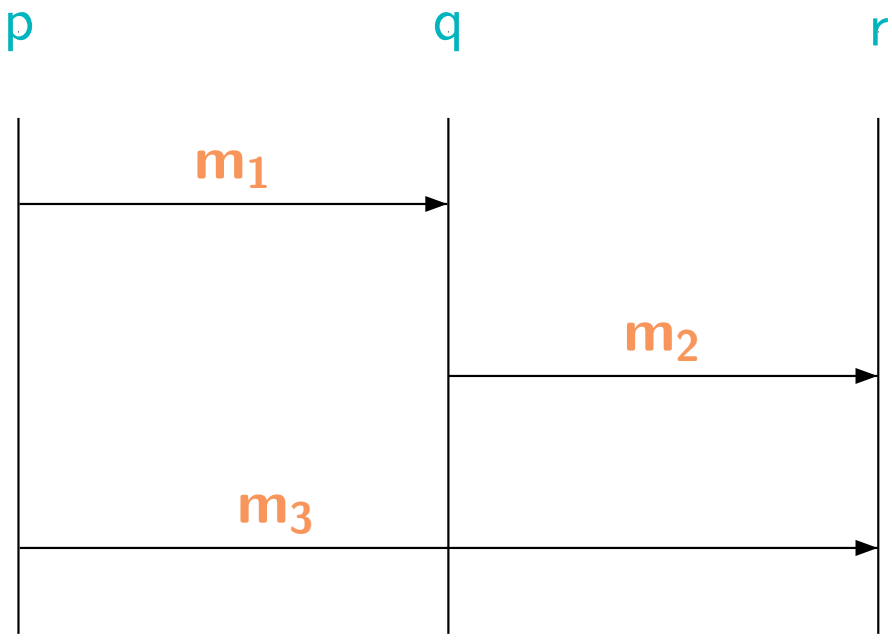
Scenarios

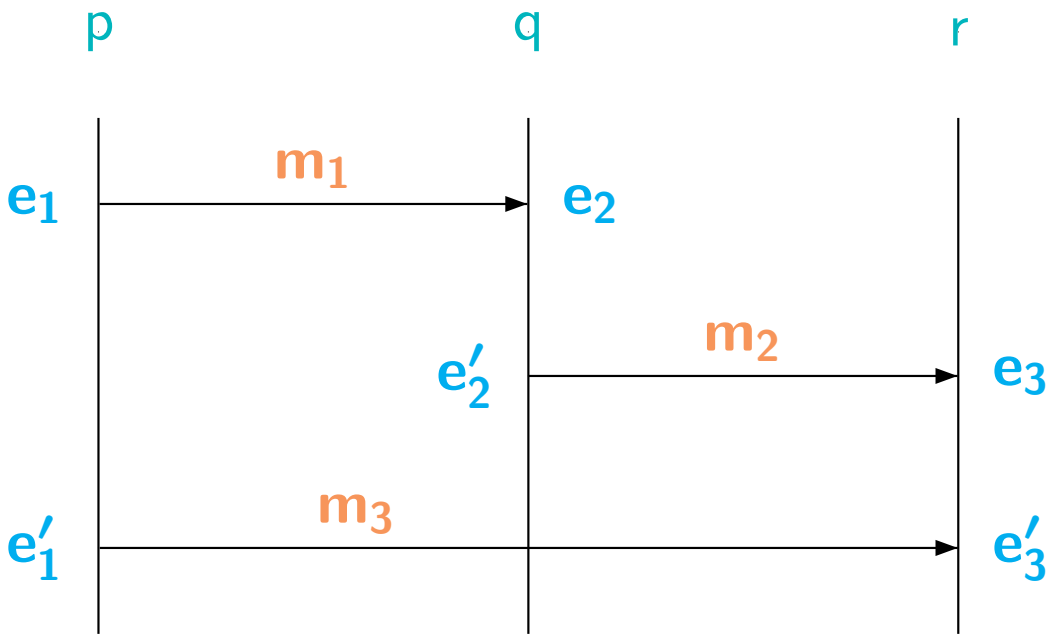
- Visual specification of message-passing system behaviour
- A scenario describes a pattern of interaction
- Telecommunications
  - Message sequence charts (MSC)
  - Messages sent between communicating agents
- UML
  - Sequence diagrams
  - Interaction between objects

    e.g., method invocations etc

An MSC



An MSC with events



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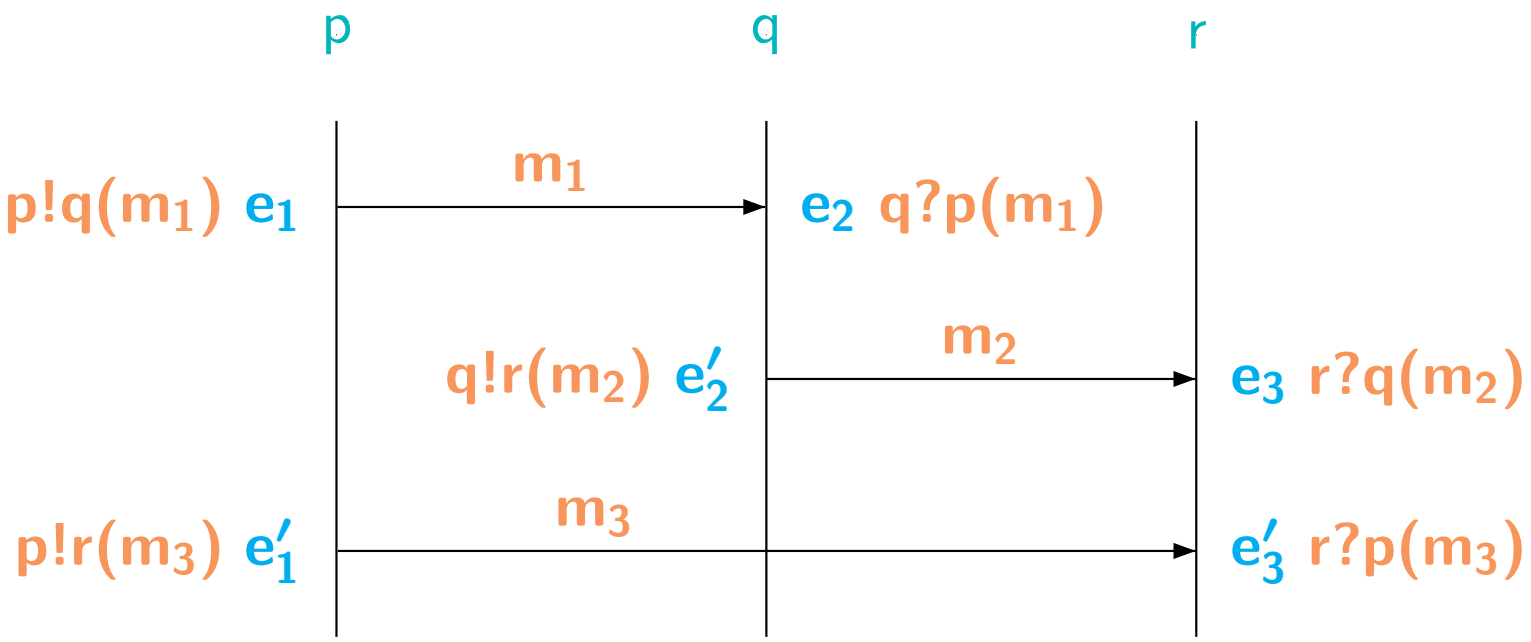
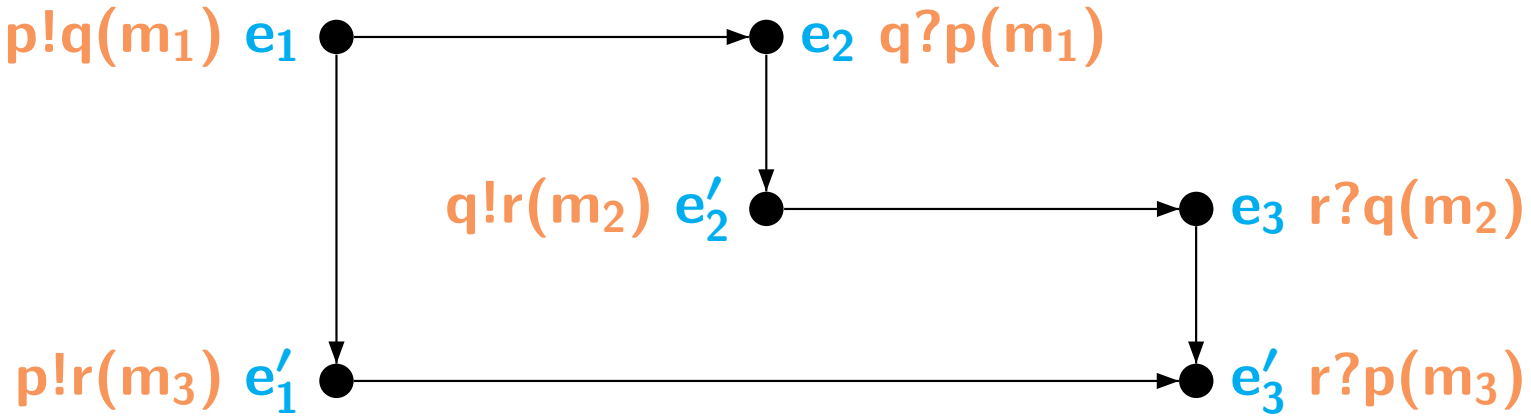


MSCs as labelled partial orders



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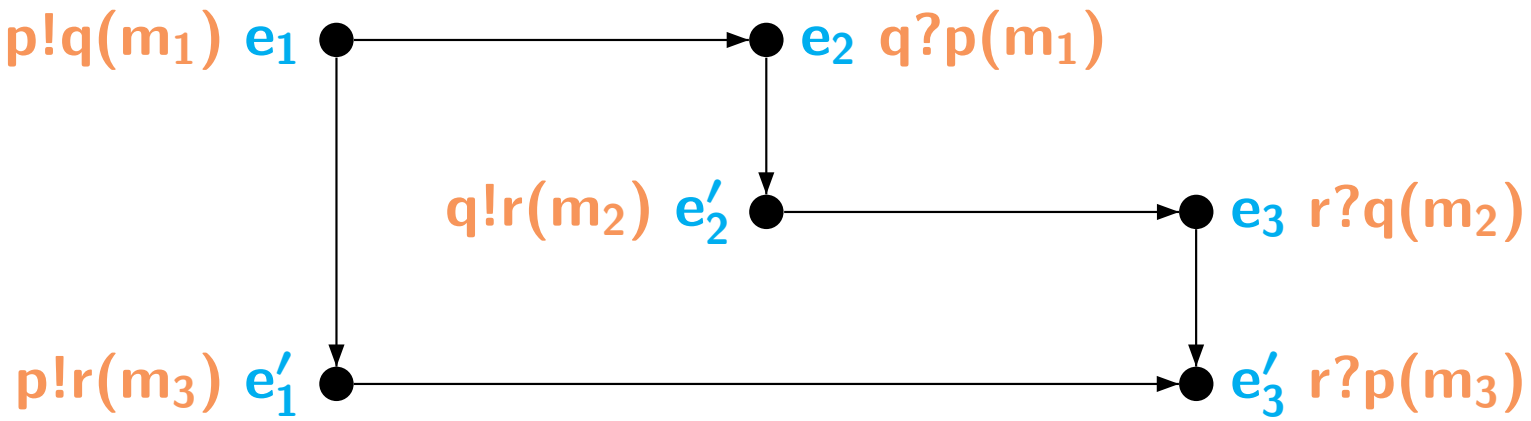

- Linearizations give a word language
  $p!q(m_1)\ p!r(m_3)\ q?p(m_1)\ q!r(m_2)\ r?q(m_2)\ r?p(m_3)$,
  $p!q(m_1)\ q?p(m_1)\ q!r(m_2)\ p!r(m_3)\ r?q(m_2)\ r?p(m_3)$,...
- A single linearization is sufficient to reconstruct MSC

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  - Selectively monitor the channels of the system
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- "Real world" testing—for example, using TTCN-3— is a version of local testing
- Does local testing suffice to check conformance for (regular) MSC specifications?

High level MSCs (HMSCs) to generate infinite collections

- A finite state automaton
- Each state is labelled by an MSC
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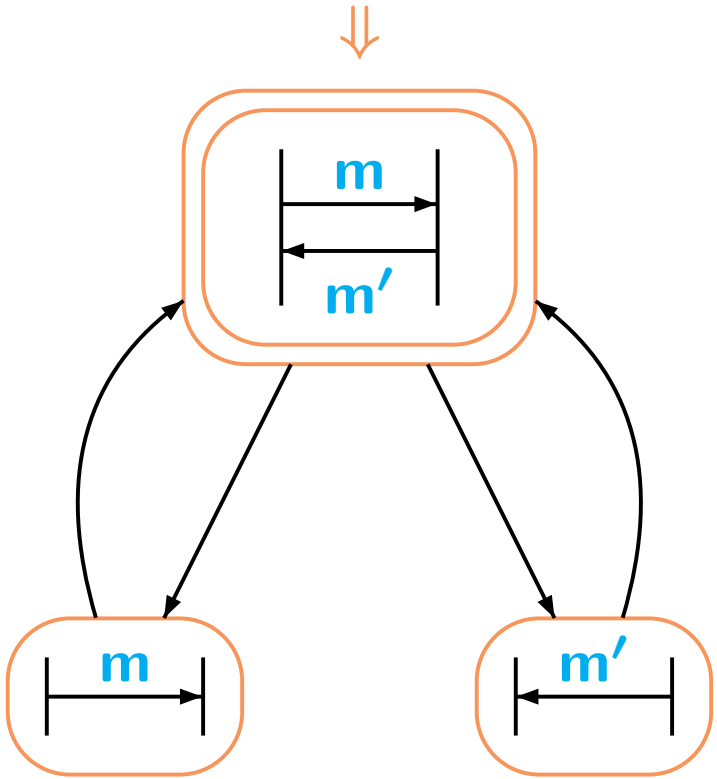

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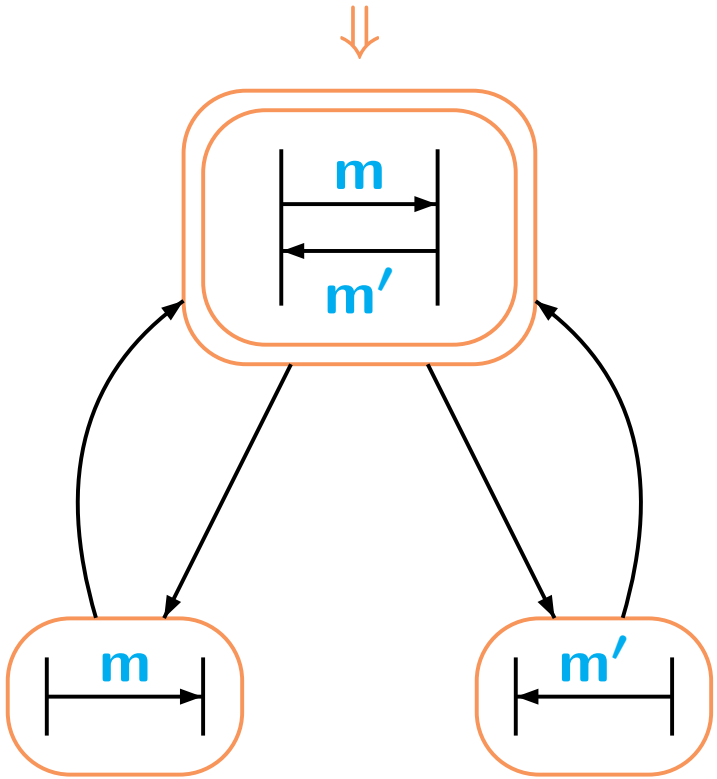

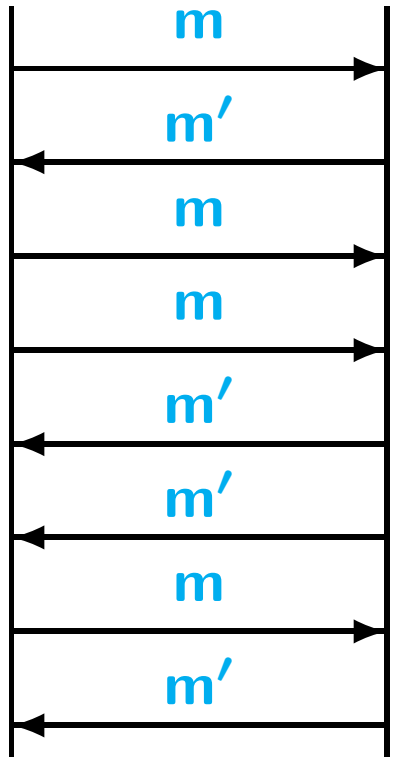

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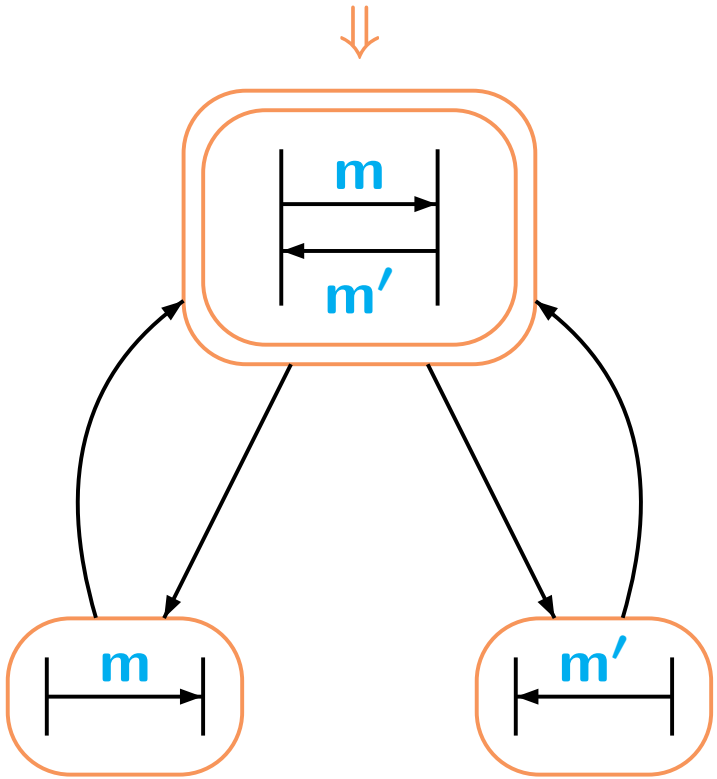

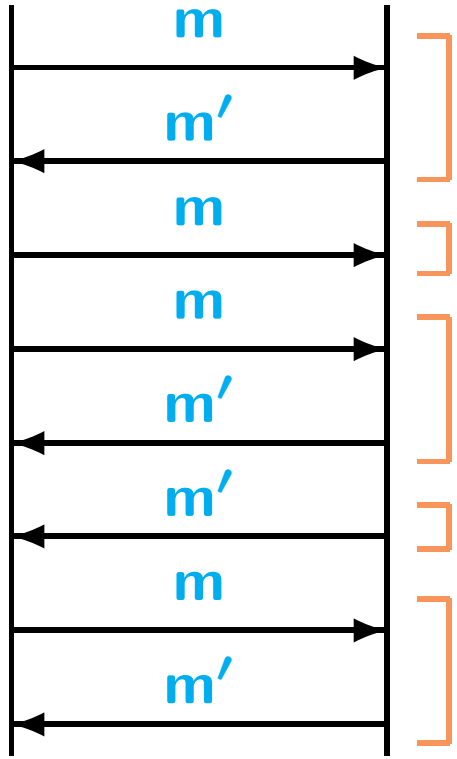

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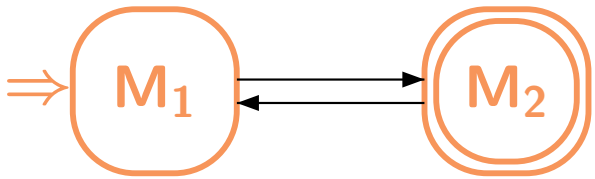

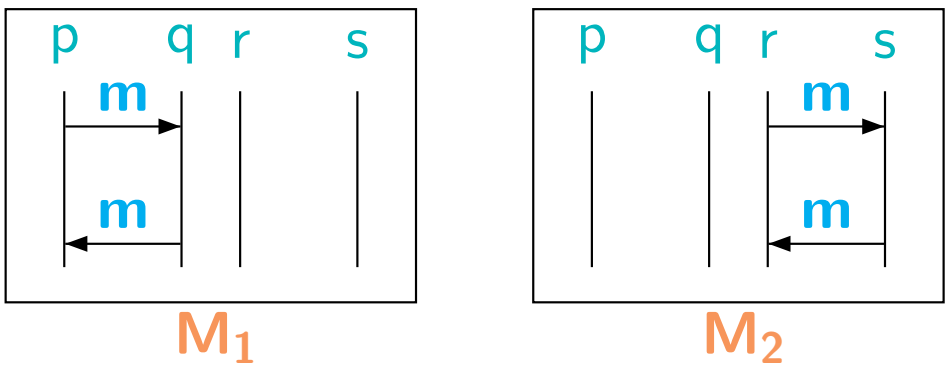

- After k iterations, we could have r and s in the final copy of M_2 while p and q are in the first copy of M_1

Regular MSC languages

- An MSC is (uniquely) determined by its linearizations
  - Set of strings over send actions **p!q(m)** and receive actions **p?q(m)**

- Collection of MSCs $\Leftrightarrow$
  word language over send/receive actions

- Regular collection of MSCs $\stackrel{\triangle}{=}$
  linearizations form a regular language

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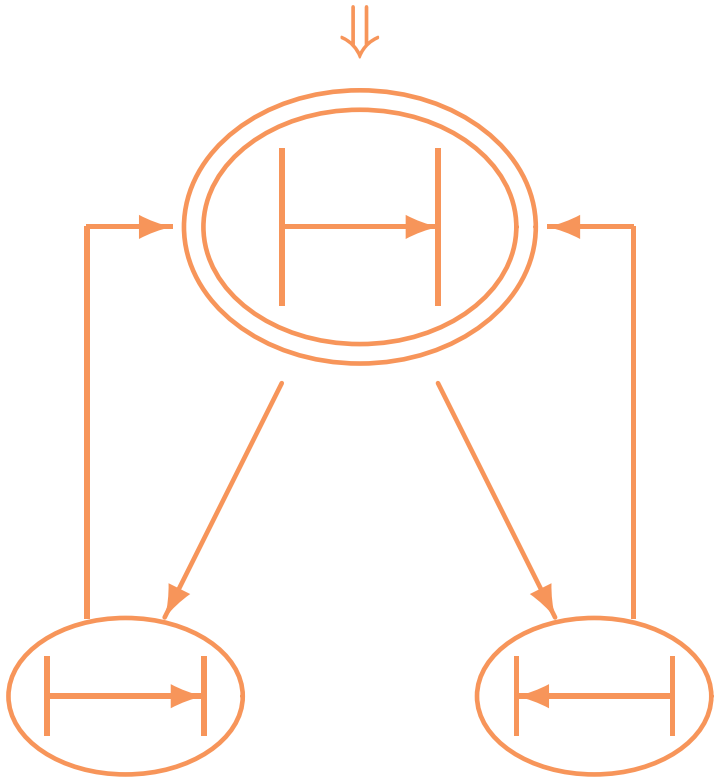

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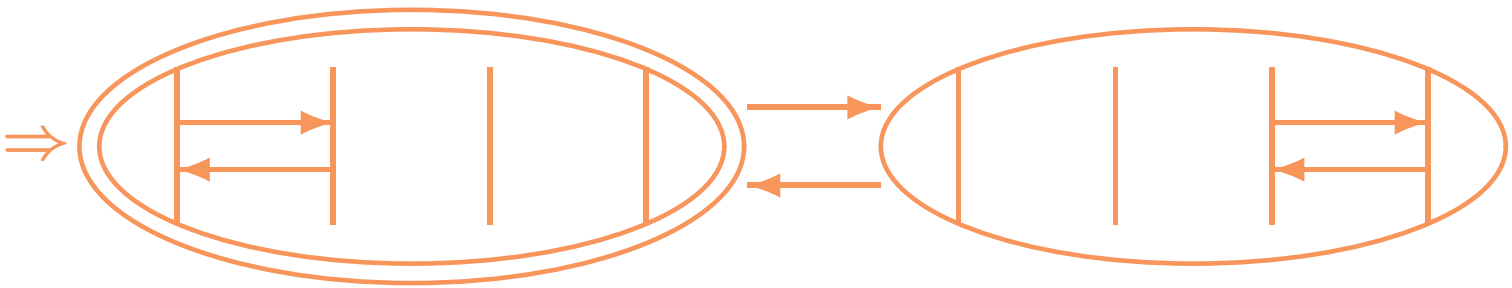

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- Sufficient structural conditions on HMSCs to guarantee regularity . . . [AY99,MP99]
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- Sufficient structural conditions on HMSCs to guarantee regularity . . . [AY99,MP99]
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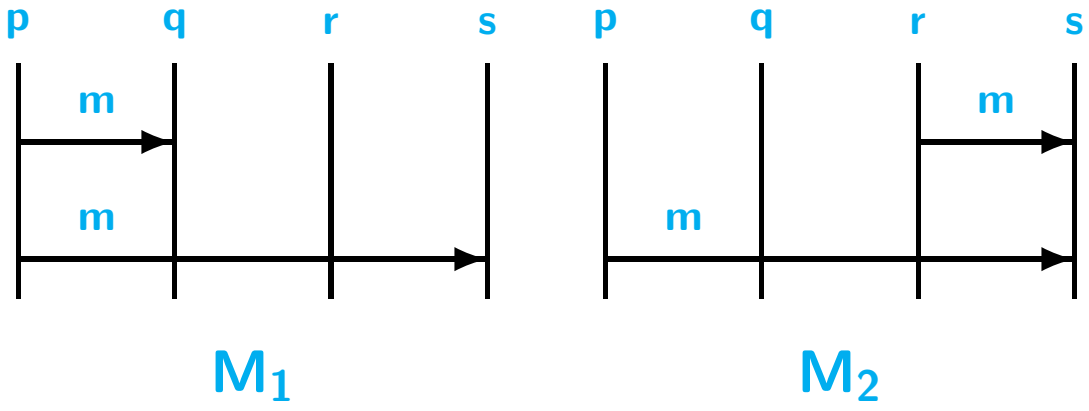
- . . . but checking if an HMSC specification is regular is undecidable [HMNST05]
- Every regular MSC language can be implemented as network of communicating finite-state automata with (universally) bounded channels [HMNST05]
- This channel bound can be computed, if needed.

Implied scenarios [AEY00]



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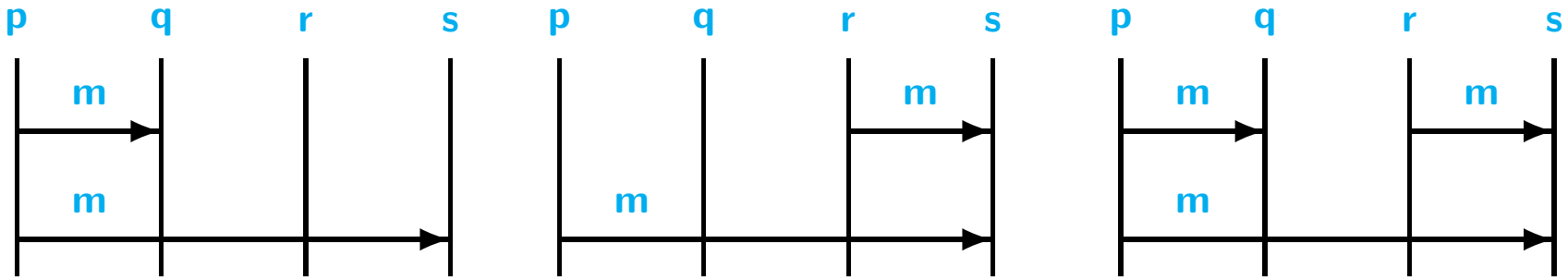

M_1 M_2 M

- **p** and **q** believe **M** is M_1
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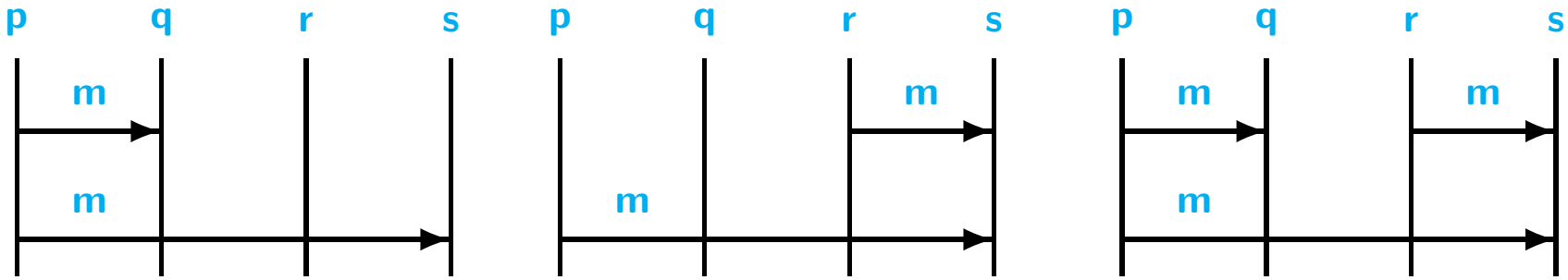

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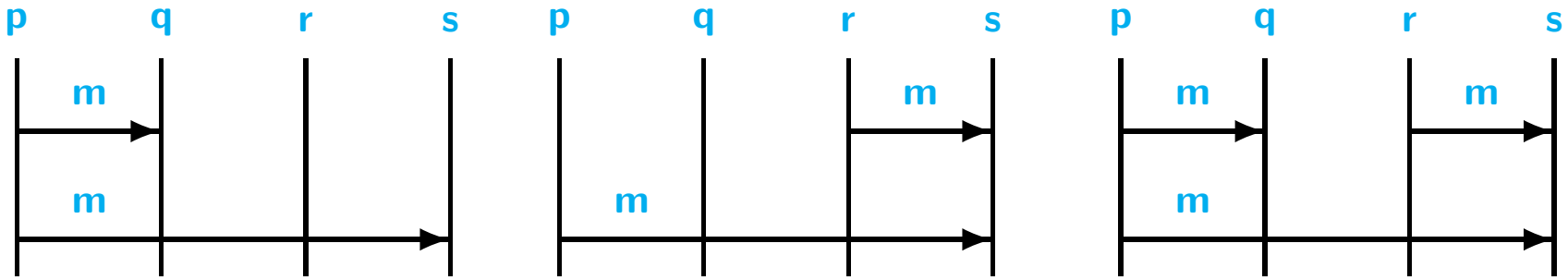

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- MSC **M** is implied by **L** if for each process **p**, the **p**-projection of **M** matches the **p**-projection of some MSC in **L**
- An MSC language is locally testable if it is closed with respect to implied MSCs

Implied scenarios . . .

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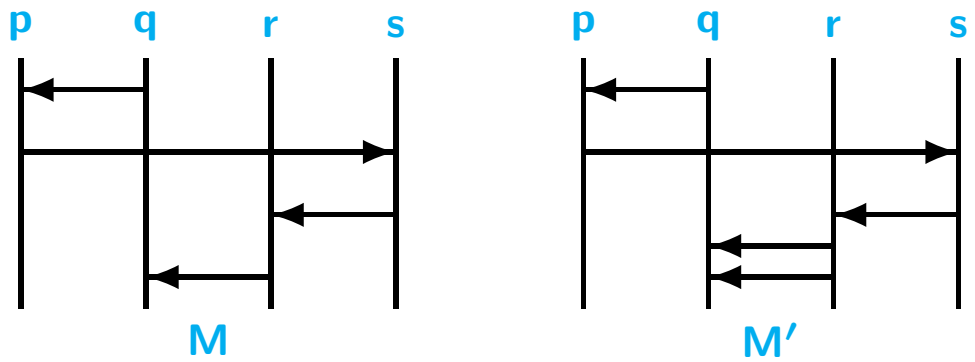

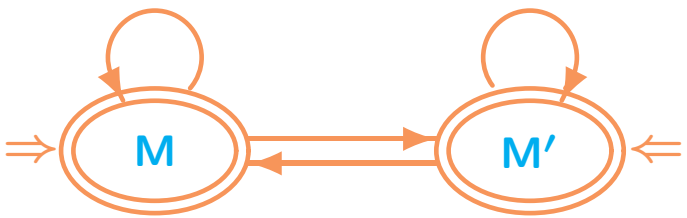

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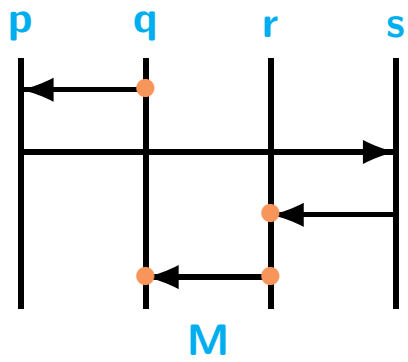
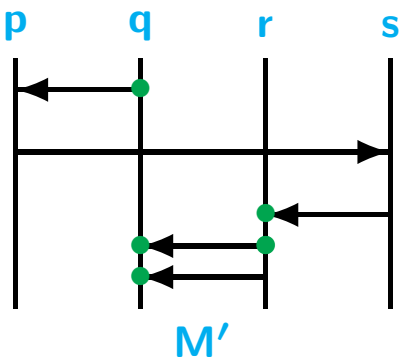
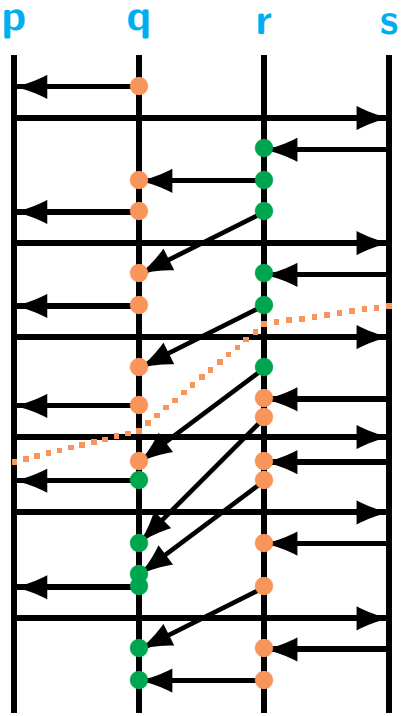




Confusing $M^{2k}M'^{k}$ and $M'^{k}M^{2k}$ generates upto k messages in $p \longrightarrow s$ channel



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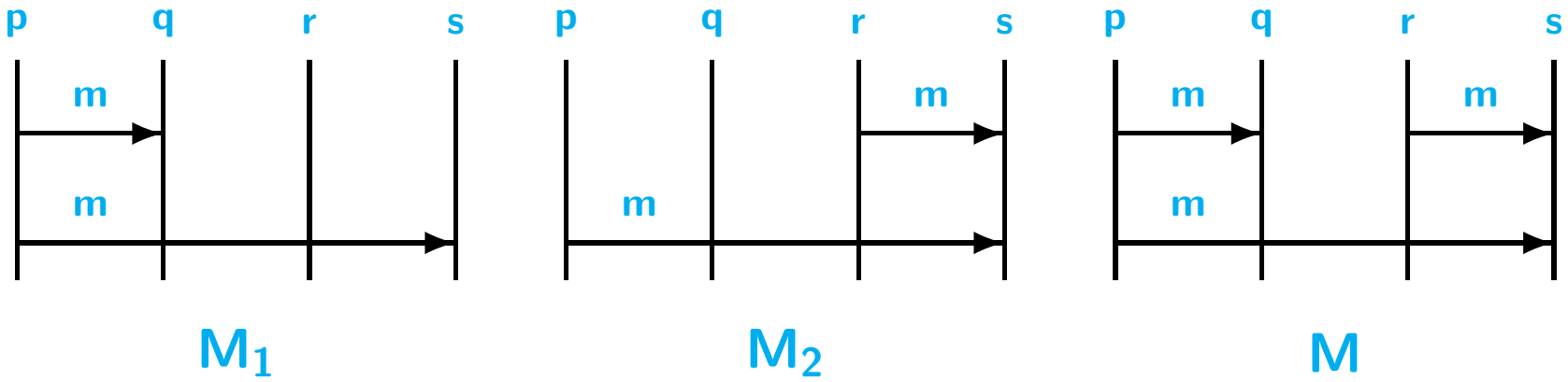

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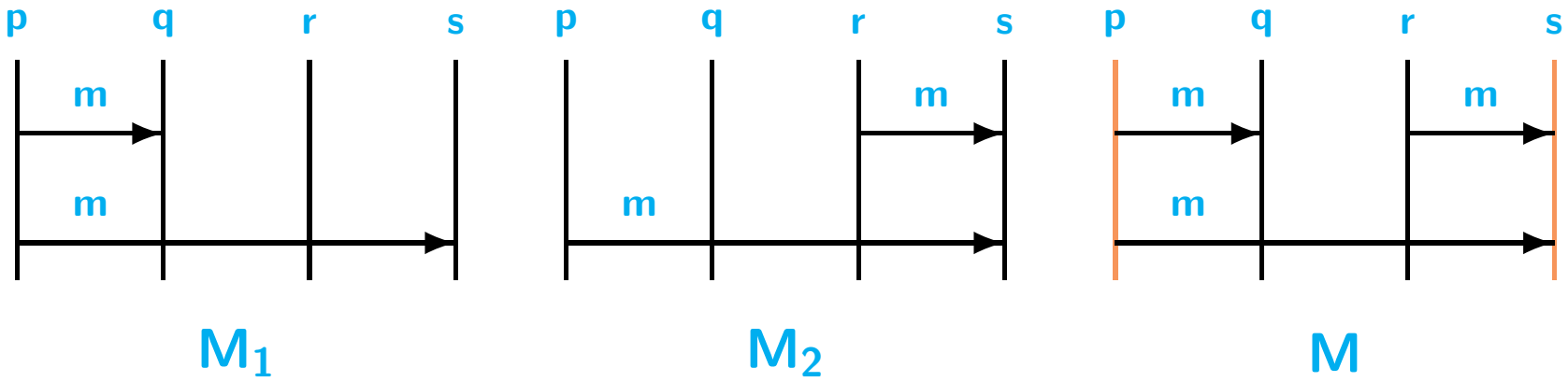

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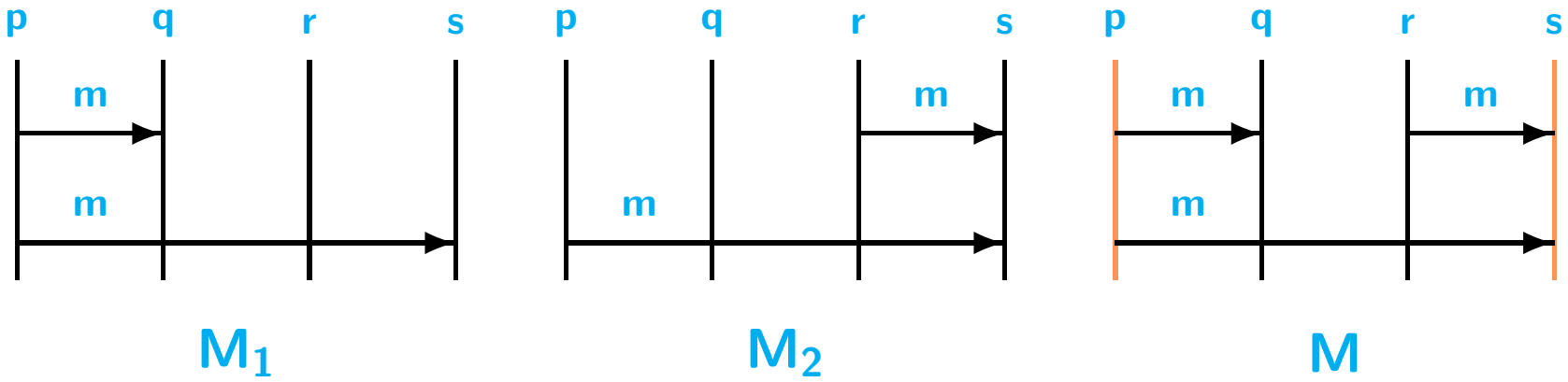

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- The testing model of concurrent TTCN-3 corresponds to local testing with joint observers.

k-testability

- Record joint observations for every set P of processes of size k.

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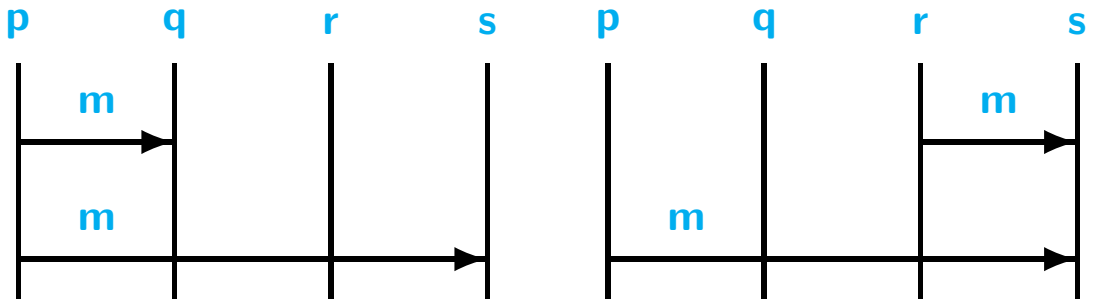
- **k**-closure of a language **L** $\triangleq$
$$\{\mathbf{M} \mid \forall \mathbf{P} \text{ s.t. } |\mathbf{P}| = \mathbf{k}.\ \exists \mathbf{M'} \in \mathbf{L}.\ \mathbf{M}{\restriction_{\mathbf{P}}} = \mathbf{M'}{\restriction_{\mathbf{P}}}\}$$
- **k**-implied scenario **M** for a language **L** $\triangleq$
MSC in the **k**-closure of **L** but not in **L**

k-testability

- Record joint observations for every set P of processes of size k.
- k-closure of a language $L \triangleq$
$$\{M \mid \forall P \text{ s.t. } |P| = k.\ \exists M' \in L.\ M{\restriction_P} = M'{\restriction_P}\}$$
- k-implied scenario M for a language $L \triangleq$
MSC in the k-closure of L but not in L
- A language is k-testable if it equals its k-closure
  - Local testability is 1-testability

k-testability . . .



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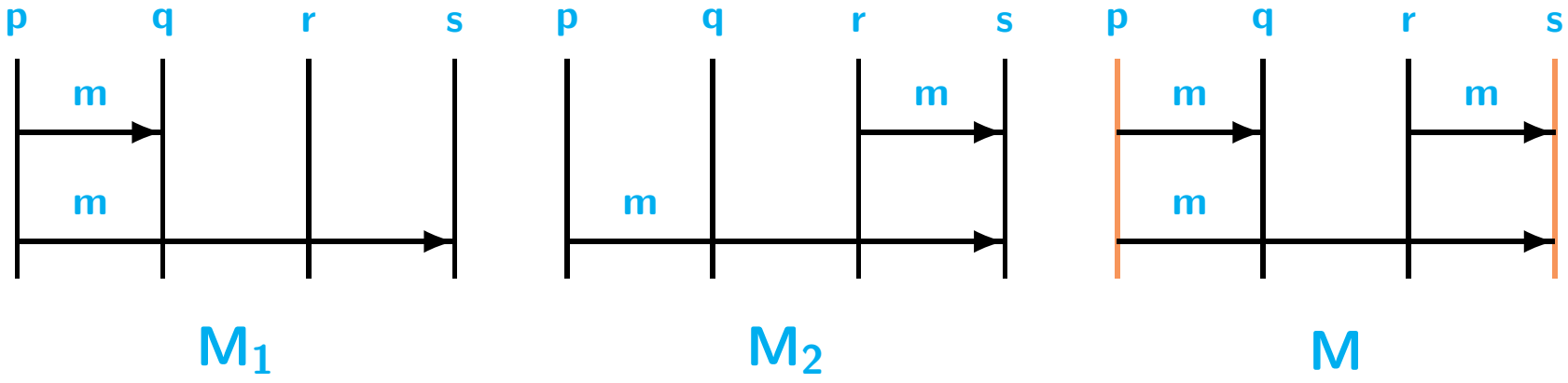
The set $\{M_1, M_2\}$ is 2-testable but not 1-testable.

k-testability . . .



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k-testability ...

- For all n and $k < n$ there are regular HMSC languages over n processes that are not k-testable
- 1-testability is undecidable for 4 or more processes. [AEY 01]
- n-testability is trivially decidable
  - What about k-testability for $1 < k < n$?
  - What is the smallest $k \leq n$ such that k-testability is decidable?

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Theorem [BGMN, FCT 2007]

- k-testability is undecidable for $n \geq 3$ processes and $1 < k < n$
- 1-testability is undecidable for 2 processes
- k-testability remains undecidable even with a one-letter alphabet for $n \geq 3$ processes and $1 < k < n$

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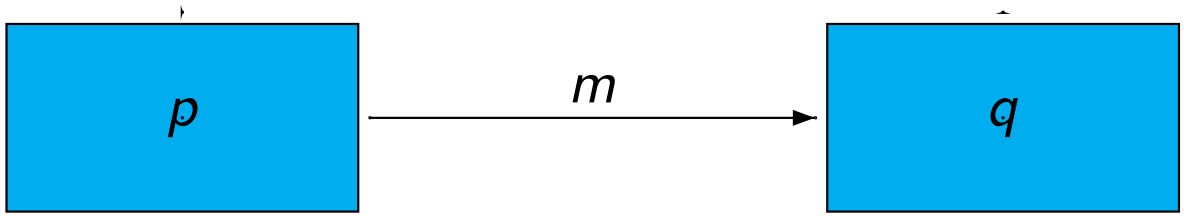

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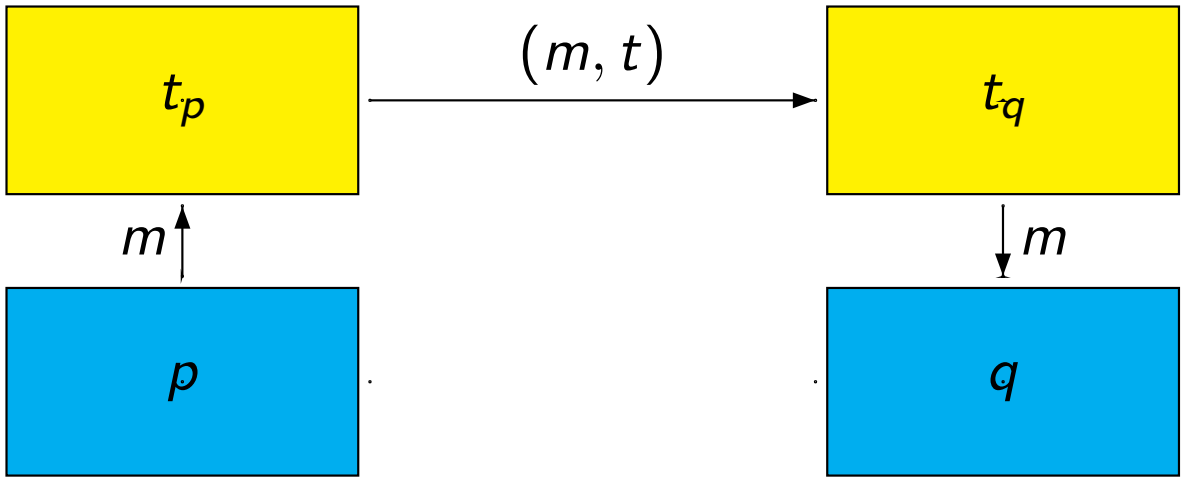
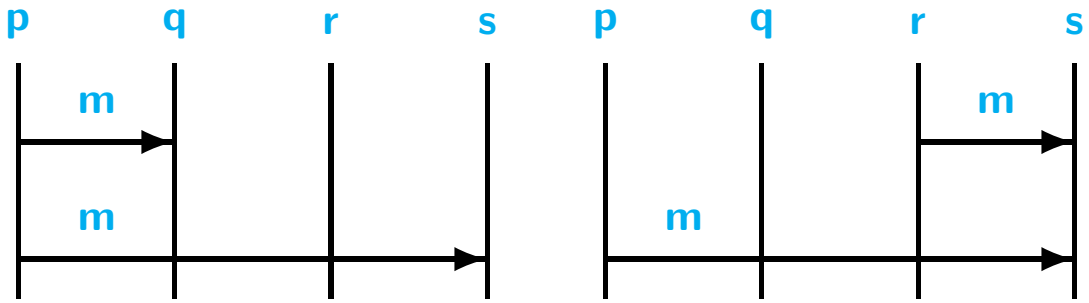


- Compare local observations of tagged system with tagged specification

Tagging for local testability . . .



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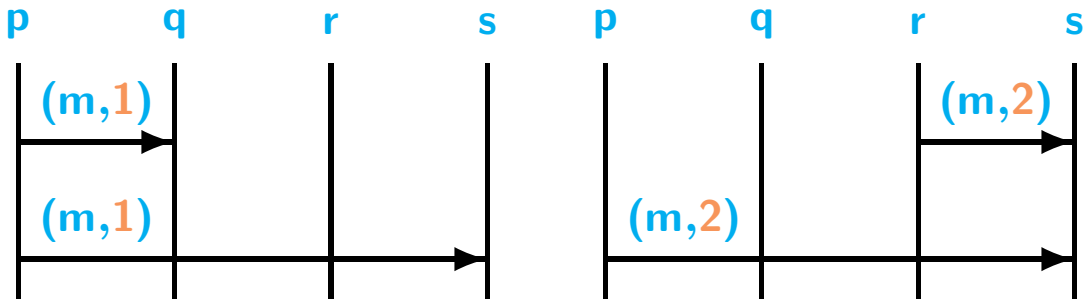

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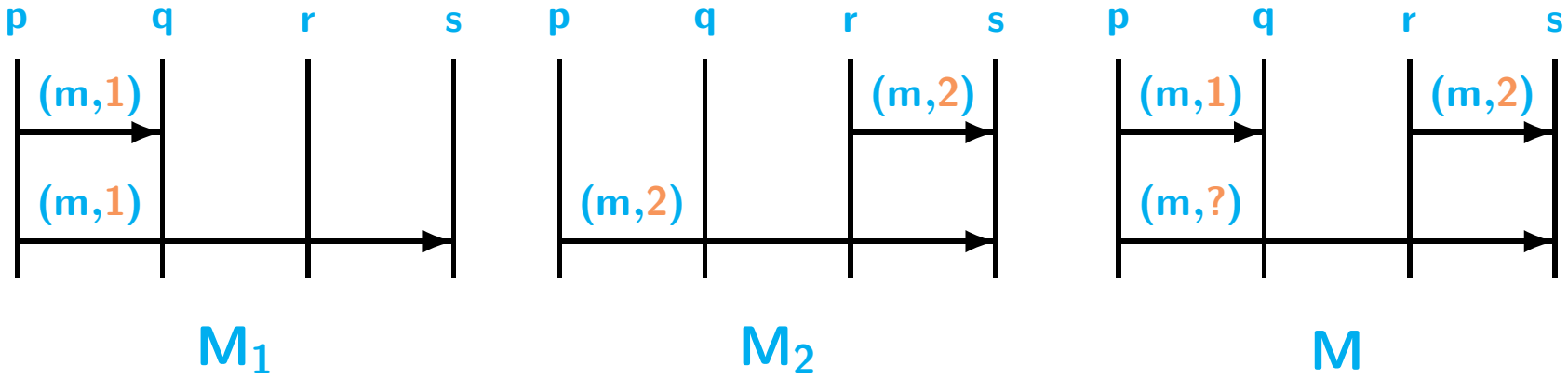
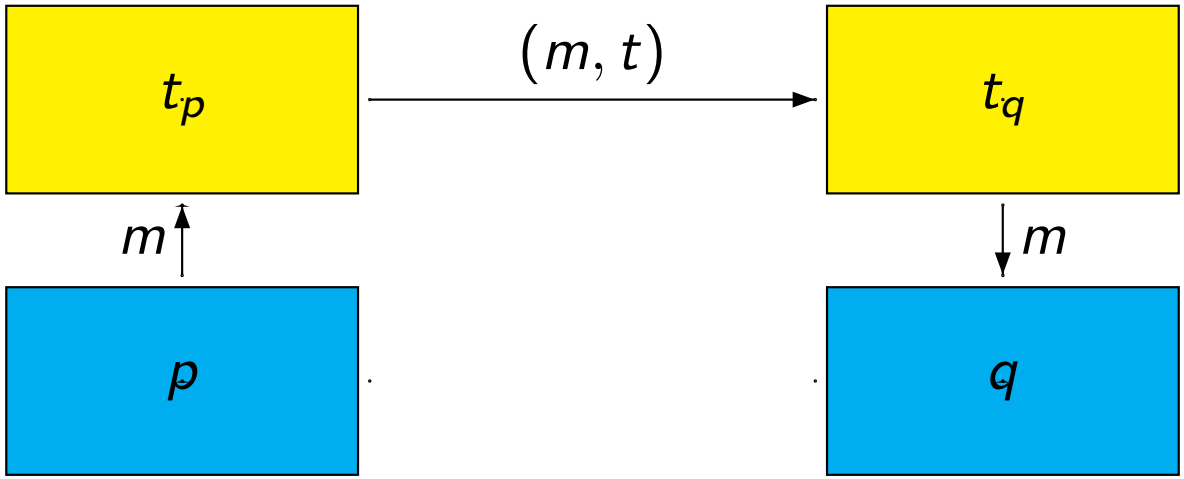


M_1 M_2 M

- By tagging auxiliary information to **m** in the specification, we know whether the message from **p** to **s** comes from M_1 or M_2
- This rules out the implied scenario **M**

Implementing tagging



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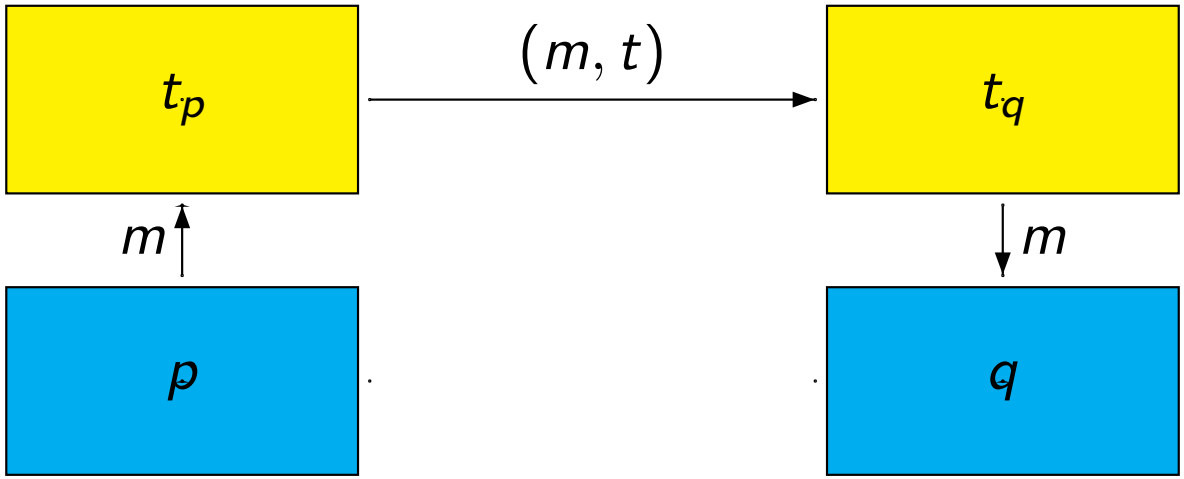

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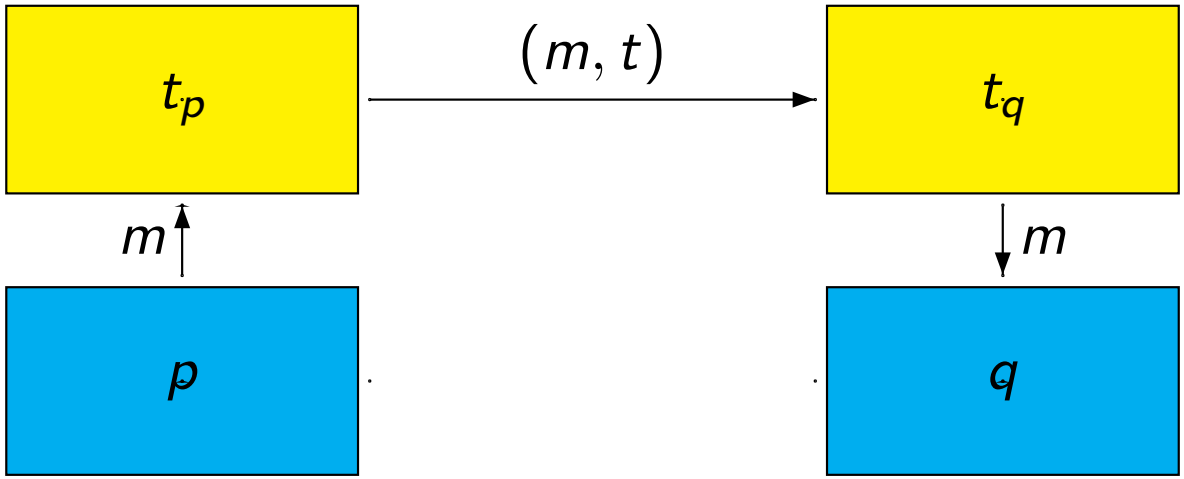

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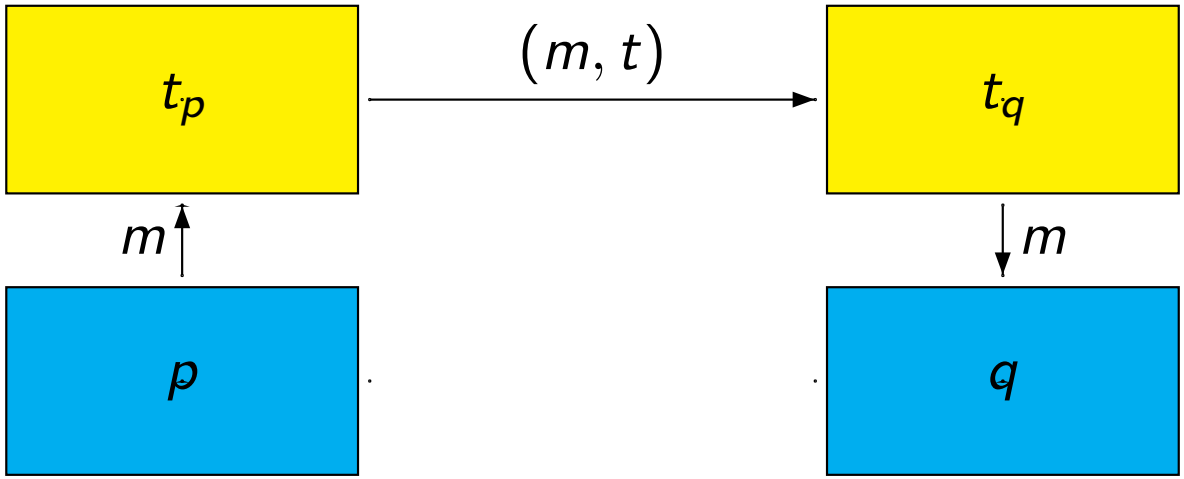

- Tagging is like adding a transport layer in a network
  - System under test is not modified
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- Analogous to compiling with debug flag
  - Adding debugging information should not modify behaviour of program

Generating tags for local testing

- How do we generate tags for messages?

Generating tags for local testing

- How do we generate tags for messages?
- Bounded timestamping protocol [MNS03]
  - Each message is assigned a label (timestamp) from a bounded set
  - Augment messages with auxiliary information
    - Implicitly records information about size of channels
    - Includes timestamps of all unacknowledged messages
    - Message sent by **p** whose receive event is not in the causal past of **p**
  - Ensure that timestamps are reused in a consistent manner
  - If underlying computation has universally bounded channels, auxiliary information on each message is bounded

Local testing with timestamps

- Add timestamps to HMSC $\mathbf{H}$ to get "unfolded" HMSC $\mathbf{H}^{\mathsf{T}}$
  - Each node in $\mathbf{H}^{\mathsf{T}}$ is a timestamped copy of a node in $\mathbf{H}$
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- System under test (SUT) is a communicating finite-state machine
  - Run SUT synchronously with bounded timestamping automaton

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- Compare timestamped runs of SUT with $\mathbf{H}^{\mathbf{T}}$

$\mathbf{H}^{\mathsf{T}}$ and implied scenarios

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  - Projections describe a CFM $\mathbf{A}^{\mathbf{T}}$ for implied scenarios of $\mathbf{H}^{\mathbf{T}}$
  - This CFM has universally bounded channels
  - Implied scenarios of $\mathbf{H}^{\mathbf{T}}$ form a regular MSC language

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- Construct a CFM $\mathbf{A}$ from $\mathbf{H}^{\mathbf{T}}$
- Compare $\mathbf{L(A)}$ and $\mathbf{L(A^{T})}$
  - Both define regular MSC languages

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- Synchronous setting : Can cover MSC specification with minimum implied scenarios [UKM01]
- Asynchronous setting : Can cover arbitrary regular MSC specifications exactly using complex timestamping [HMNST05]
- Tagging can offer an intermediate solution
  - Synthesize CFM by combining projections modulo tagging
  - Tagging is deadlock free — will produce a deadlock free implementation if one exists

Connection with causal closure

- Timestamping approach motivated by work on causal closure of HMSCs [AMNN05]
- Causal view of a process **p** of MSC **M** is set of events causally below maximum **p** event in **M**
- Causally implied MSC — causal view of each process is consistent with some MSC in the language
- Casual closure of a regular MSC language is regular
  - Use timestamping to show this, but . . .
  - . . . timestamps must be integrated into CFM
- For local testing, timestamping is oblivious to structure of CFM

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- Maximally discriminating tagging schemes vs minimally implementable ones
- Complex timestamps blow up the specification
  - Increases the lengths the local tests to be performed
- Can we design more efficient tagging schemes?
  - For instance, one tag per node in the HMSC
- Implementation under test is untagged
  - Need to be able to generate tags on the fly while testing

Summary and future work

- HMSCs — mechanism for specifying collections of scenarios
  - Attractive visual formalism
  - Sufficient condition for regularity
- Local testability is generally undecidable for the original specification
- Tagging specification with timestamps make local testability decidable
- What is the "optimal" way to tag a system?
  - Adding expressiveness increases complexity of testing
- Can we design more efficient tagging schemes?
  - Need to generate tags on the fly