Centrum voor Wiskunde en Informatica

Performance Analysis of Reo Circuits

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CIC 2007

Research Workshop on Coinduction, Interaction and Composition

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Overview

- Introduction / motivation
- Continuous Time Markov Chains
- Reo Coordination Language
- Quantitative Reo
- Performance Analysis of Reo Circuits
- Performance Analysis Example
- Future Research / To Do

Introduction

- Quantify performance of complex coordination systems
  - Communication networks, Web based services, etc.
- Typical questions:
  - Recognize bottlenecks?
  - Expected delay of the network?
  - Expected throughput?
  - Availability, blocking?
- Take into account:
  - Complex stochastic behaviour
  - Component dependencies of such systems
  - Quantitative behaviour environment

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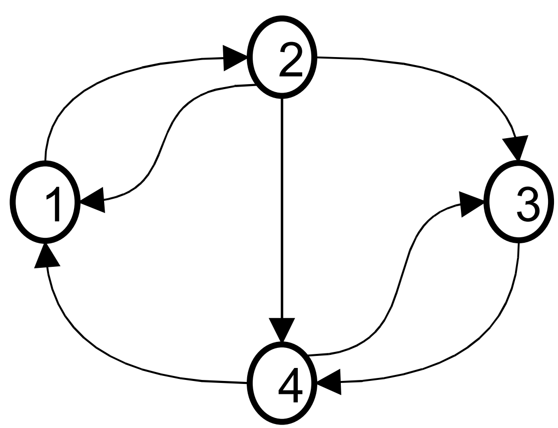
Continuous Time Markov Chains

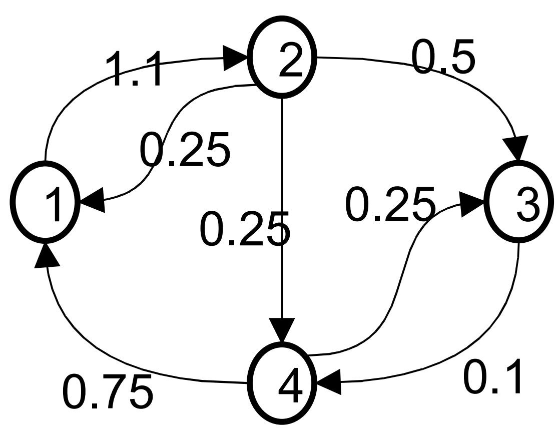
- Model coordination system as CTMC, then
- Quantify performance by using CTMC

- Markov Chain:
  - System can be in one of several states: state space
  - Transitions from one state to another



Continuous Time Markov Chains

- CTMC more concrete: Stochastic process { X(t) : t ≥ 0 }
- Process satisfies: - Markov property
  - X(t)   S   (finite state-space)
- Continuous: process defined for every time unit t ≥ 0
- Markov property: Only present state needed to determine transitions to next states → transitions with certain exponential transition rates (average # transitions per time unit)



Continuous Time Markov Chains

- Use CTMC to model complex coordination systems, and quantify performance

- Interested in long run behaviour CTMC
- Calculate steady-state probability vector:
  Probability CTMC is in a certain state at a random moment
- From steady-state probability vector →
  Calculate expected blocking probability, throughput, delay.

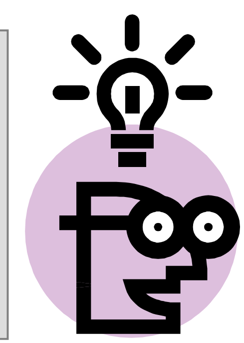
Continuous Time Markov Chains

- If we use CTMC to model system: find and define appropriate state description:
  - Finite state-space
  - Satisfies Markov property

Problems:

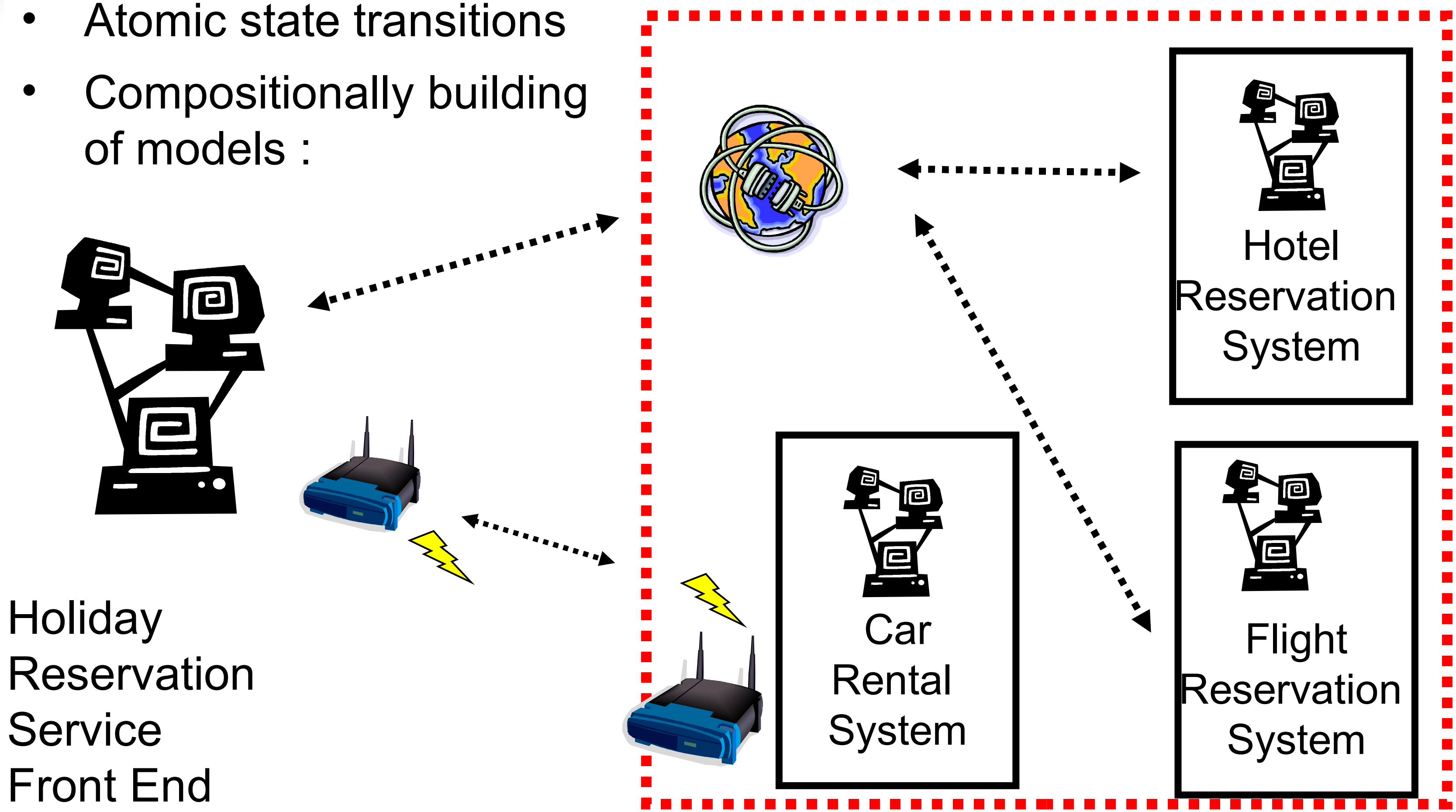
- Construction appropriate CTMC is complex
- Often leads to state-space explosion

- Idea:
  - Use Reo Coordination Language to model complex coordination systems
  - “Translate” Reo → CTMC
  - CTMC Performance Evaluation



Use the advantages of Reo:

- State-space reduction: strong synchronizing properties Reo
- Atomic state transitions
- Compositionally building of models :



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Reo Coordination Language

- Powerful means to model complex coordination systems
- Channel based coordination model, with synchronising / a-synchronising properties
- Compositional construction of models using architecturally meaningful primitives → Complex coordinators (connectors) compositionally build out of simpler ones
- Arbitrary set of simple connector types available, with well-defined behaviour
- Loose coupling of components
- Supports heterogeneous components
- Strong formal semantics

Reo Coordination Language

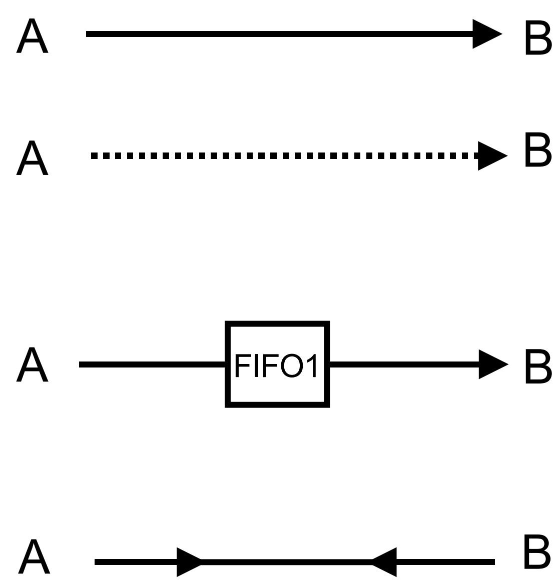
- Reo components connected through connectors (composition of simpler connectors)
- Most primitive connector is a channel (well defined behaviour):

Synchronous Channel

LossySync Channel

FIFO Channel

SyncDrain Channel



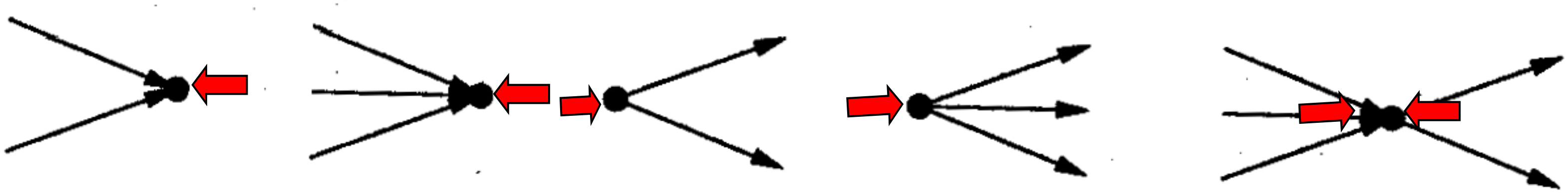
Etc.

Reo Coordination Language

Reo Nodes:

- Logical construct representing topological properties of a set of channels
- Regulates flow of data among channel ends

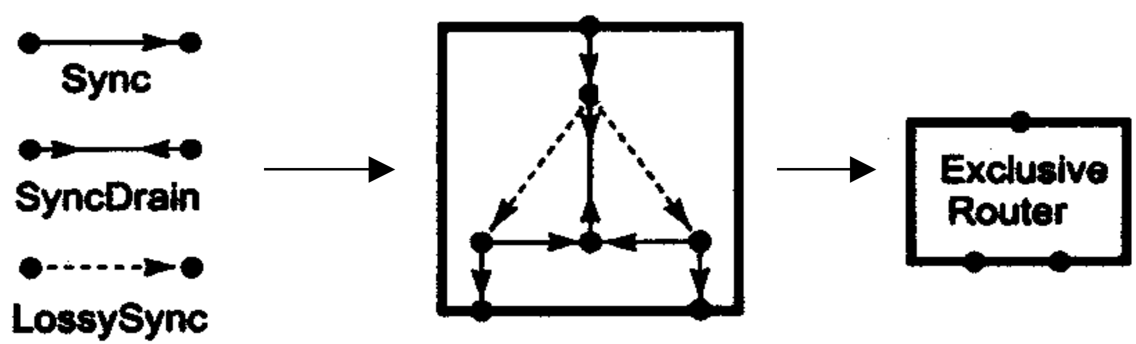
Sink Node	Source Node	Mixed Node



Arrival take actions (data dispersion))	Arrival write actions (data acceptance)	Arrival write/take actions

Reo Coordination Language

- Compositional building of models using architecturally meaningful primitives



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Quantitative Reo

- No quantitative stochastic behaviour in Reo circuits
- Ad performance properties to functional primitives:
  - Channels with delays
  - Ports with interarrival times between arriving read and write actions

Quantitative Reo: Channel Delays

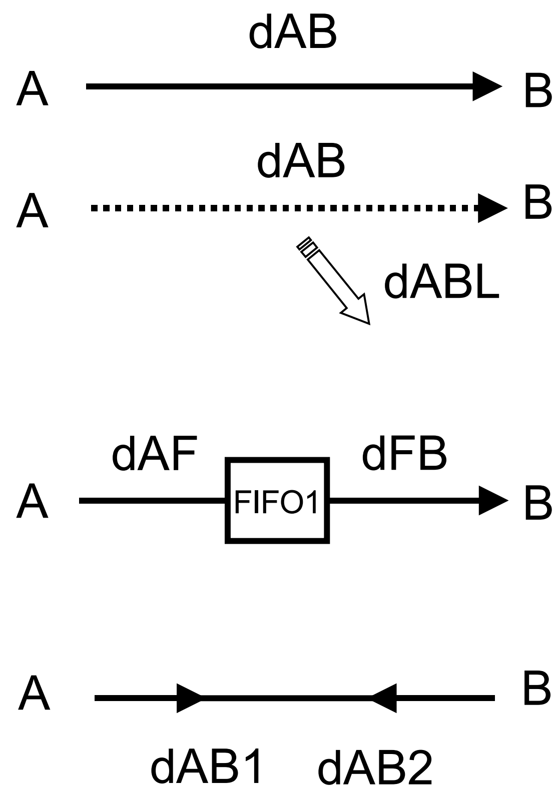
- Time it takes for a channel to synchronise with corresponding nodes

Synchronous Channel

LossySync Channel

FIFO Channel

SyncDrain Channel

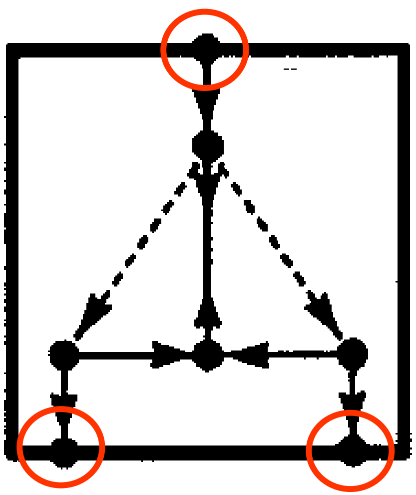


Quantitative Reo: Ports

Ports: source and sink nodes whereby circuit interacts with surrounding

Assumptions:

- Interarrival times of arriving read and write actions at ports can be specified
- Actions stay pending at ports until accepted
- At most one action can wait for acceptance at each port



- Blocking
- Denial write actions

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Performance Analysis of Reo Circuits

A. Construct quantitative Reo model

B. Use a special quantitative operational semantics for Reo language: Quantitative Intentional Automata (QIA)

C. Translate into CTMC:

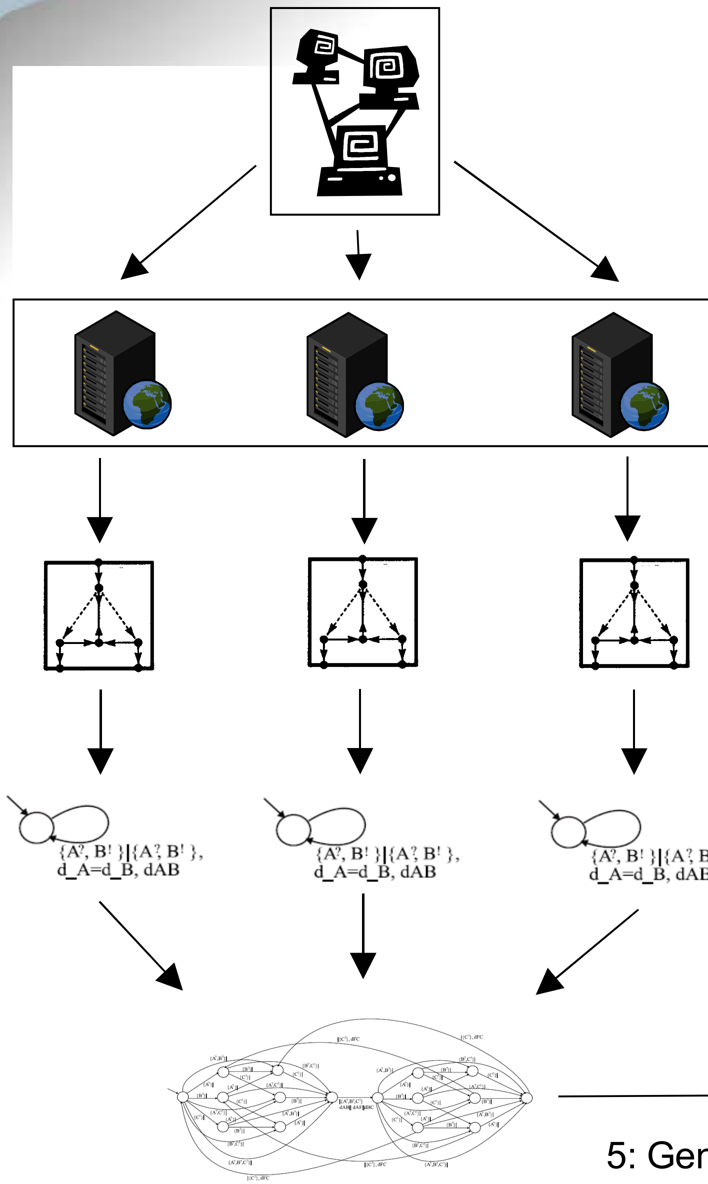
- CTMC State-space: all possible states of the Reo circuit Take into account:
  - State of ports
  - State of individual connectors (delay, buffers)
- Channel delays: independent exponentially distributed
- Interarrival times of arriving read and write actions at ports: independent exponentially distributed

Performance Analysis of Reo Circuits

D: Given steady-state distribution vector of CTMC:

- Insight in essential states, sensitivity analysis
- Approximate, e.g.:
  - Expected Blocking probabilities
  - Expected Delay: delay (sojourn time) after arrival at an arrival accepting port until arrival leaves the system
  - Expected Throughput: expected number of write requests on a certain port a circuit is able to handle per time unit

Overview: Performance Analysis of Reo Circuits



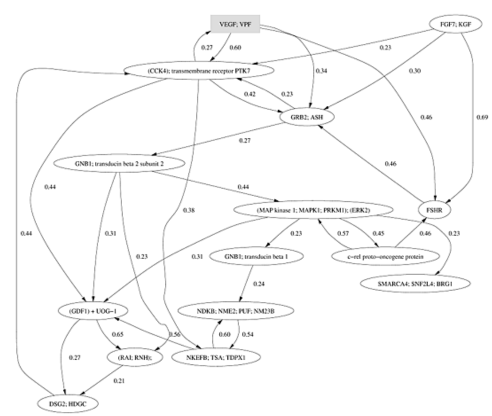
1: Decompose system

2: Reo Modeling

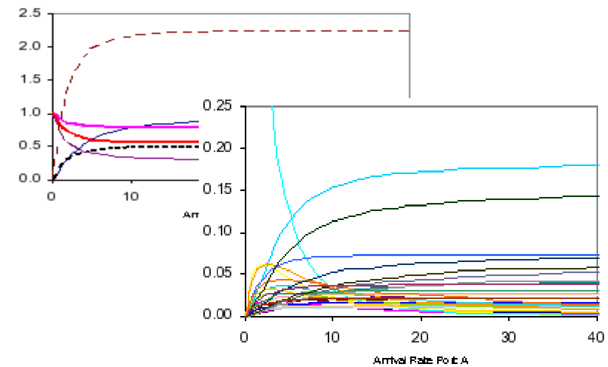
3: QIA Translation

4: Combine QIAs

5: Generate MC



6: Analyze MC



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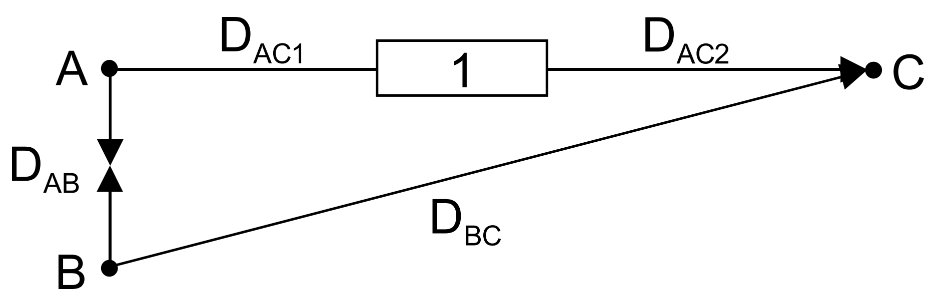
Performance Analysis Example

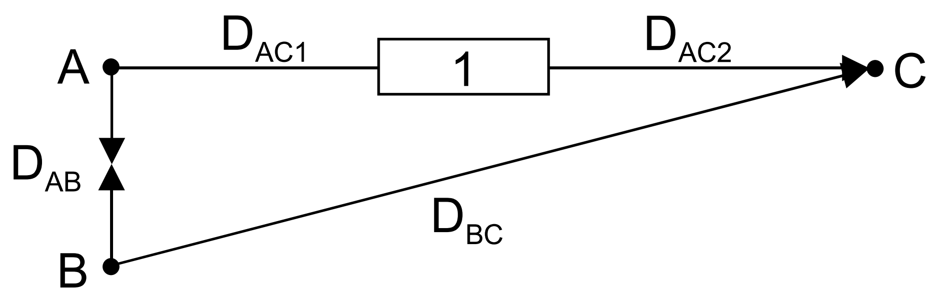
- Alternator:
  - Input ports: A, B
  - Output port: C
  - Delivers through port C, alternating what is available through A,B
- Reo Model:



- Data only accepted to flow from A into buffer:
  buffer empty, write pending at port B, read pending at port C

Performance Analysis Example

- Construct CTMC with:
  - Exponential connector delays: DAC1, DAC2, DAB, DBC
  - Exponential write action arrival rate at ports A, B
  - Exponential read action arrival rate at port C



Performance Analysis Example

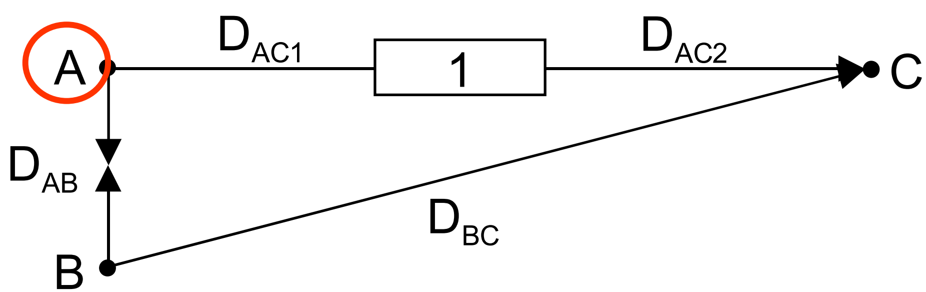
- Two examples:
  - Sensitivity analysis port A → vary mean arrival rate (=1/inter arrival time)
  - Sensitivity analysis delay BC→ vary mean delay

  - What will happen with: delays, blocking probabilities, steady-state distribution, throughput?

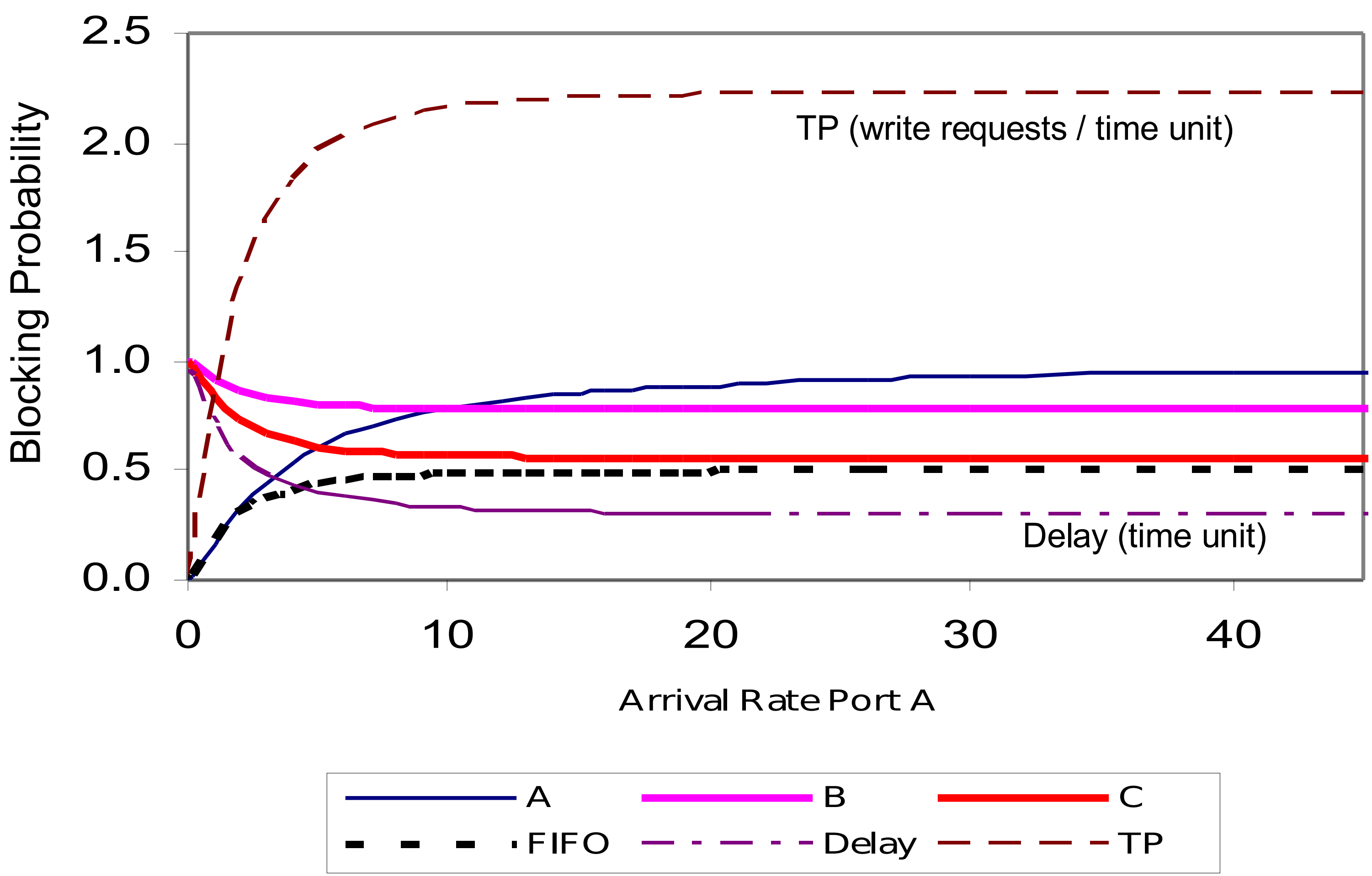
Performance Analysis Example

Sensitivity analysis port A:

vary mean arrival rate (=1/inter arrival time)



Performance Analysis Example: Port A



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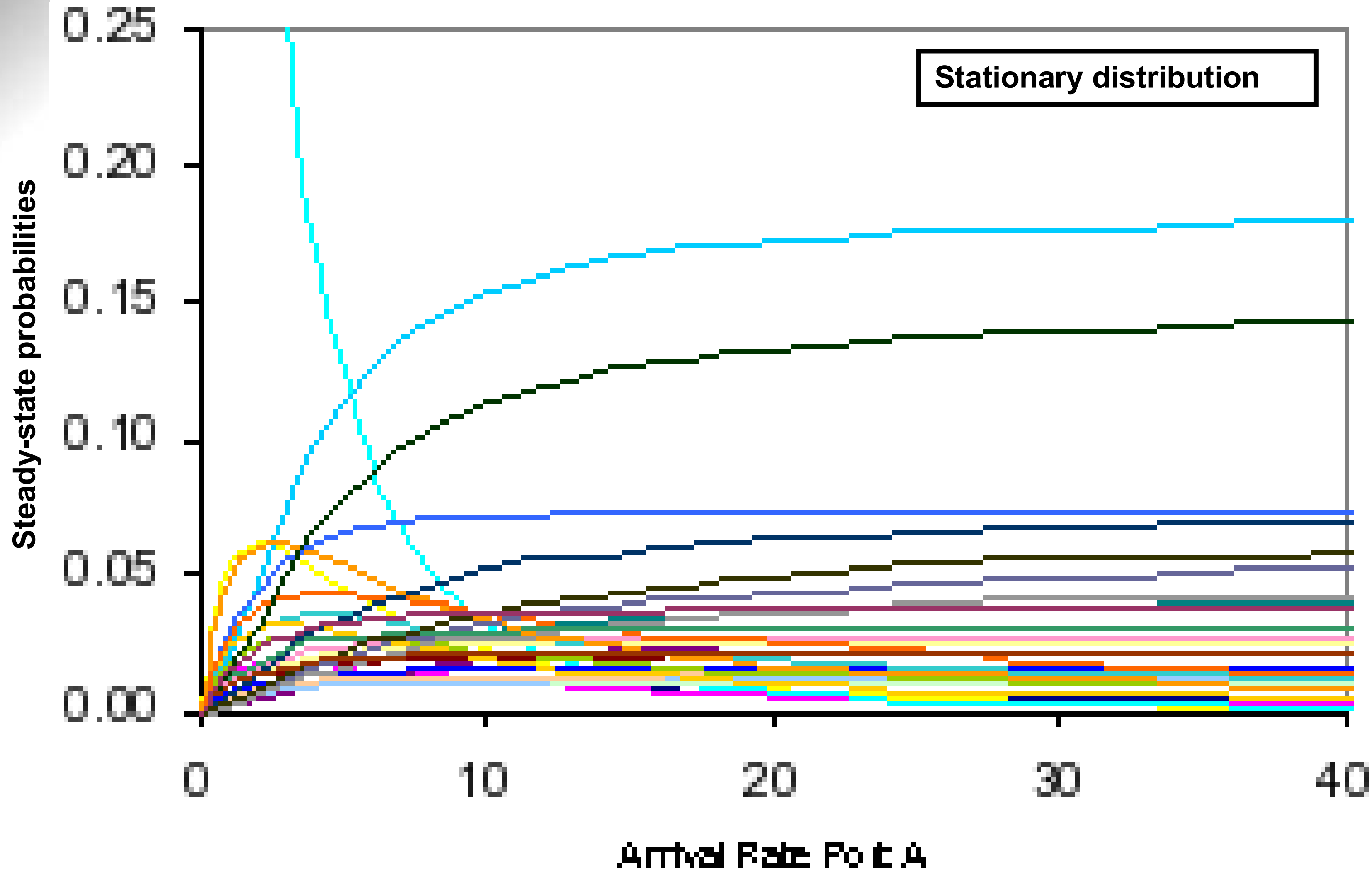
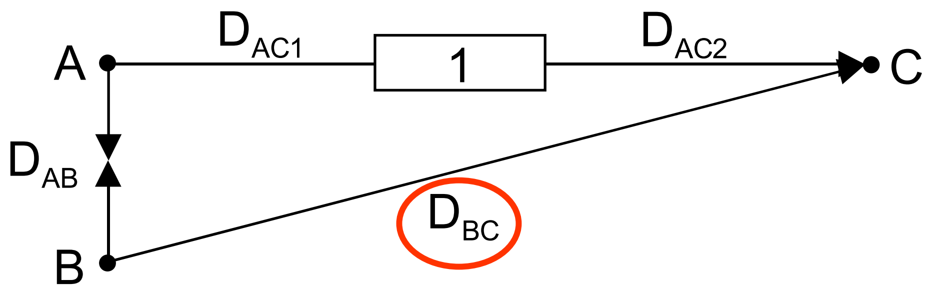
Performance Analysis Example: Port A



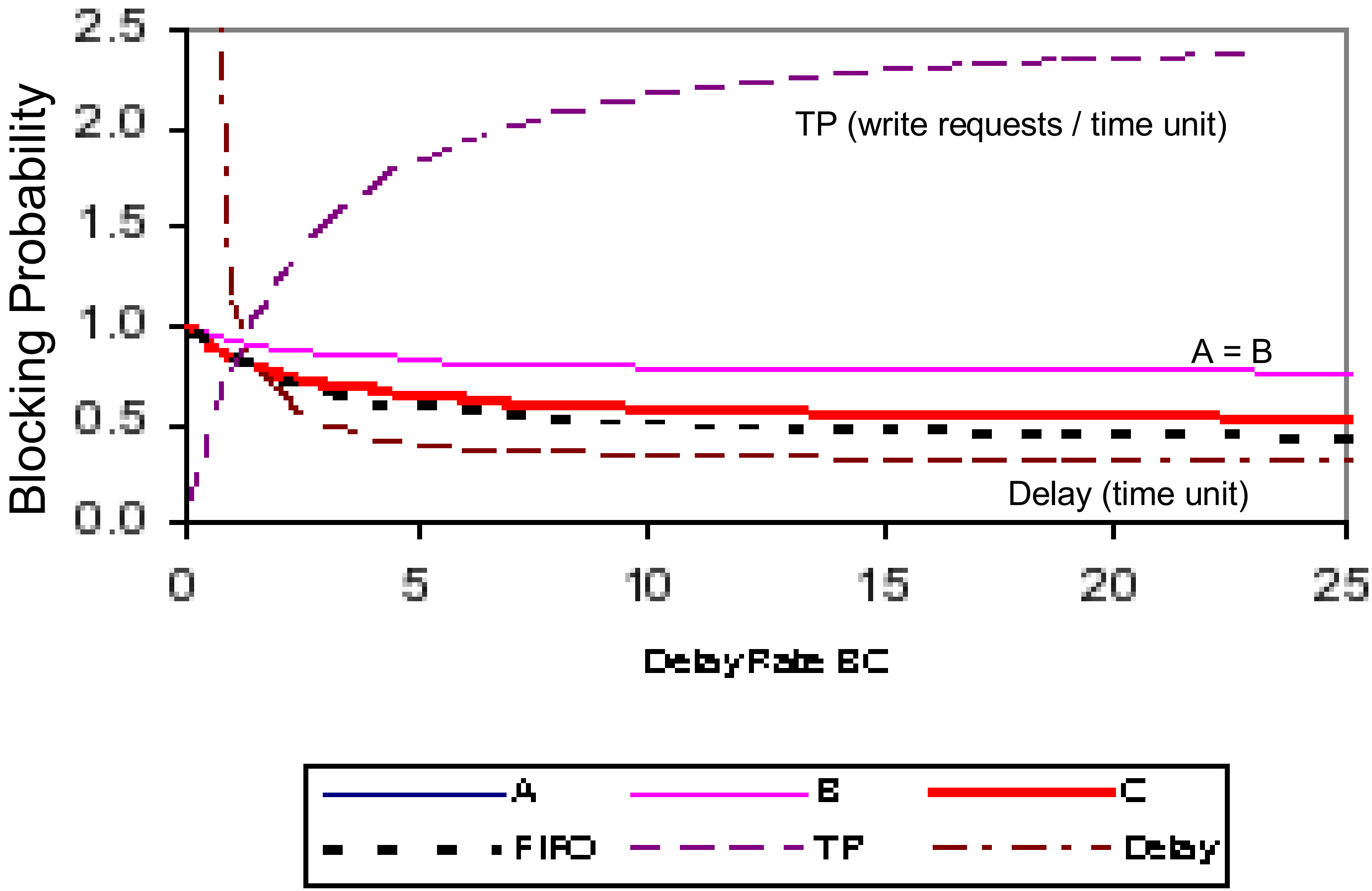
Performance Analysis Example

Sensitivity analysis delay BC:

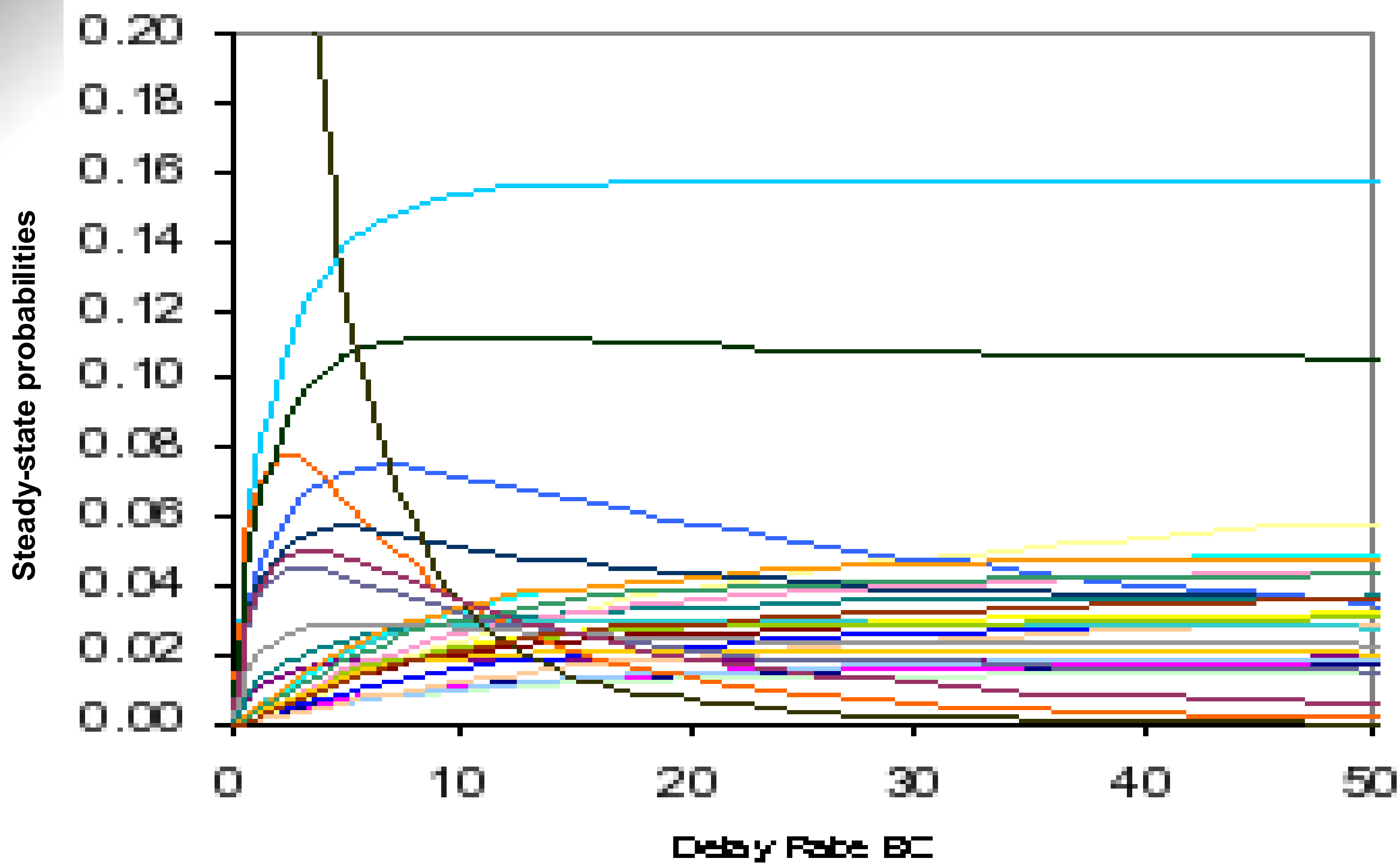
vary mean delay



Performance Analysis Example: Delay BC



Performance Analysis Example: Delay BC



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Further Research / “To Do”:

- Finish “automated” Reo-CTMC algorithm (QIA, QIA to CTMC)
  - → Current status: next presentation Young-Joo Moon
- Handle non-exponential distributed arrivals and delays?
- Introduce Reo nodes with delay? Now only delay on channels
- Calculate optimal policies for the behaviour of mixed nodes? Instead of completely randomized mixed node behaviour
- Recognize important states of Reo sub circuits and simplify CTMC by making approximations for those subsystems?

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