CS 735: Formal Models for Concurrent and Asynchronous Systems

– Introduction

Instructor: S. Akshay

Jan-Apr 2024

Course hours: Slot09,
Mondays and Thursdays 3:30-5:00pm
Office hours: To be announced

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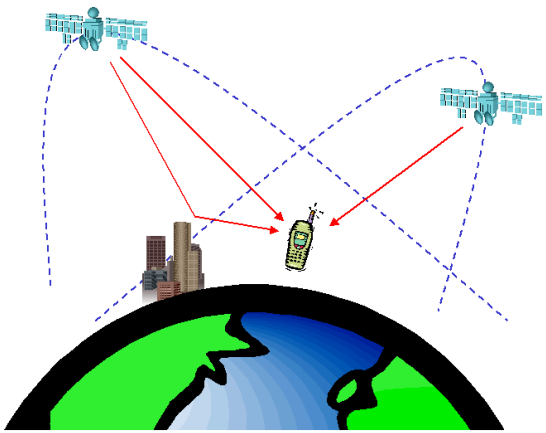
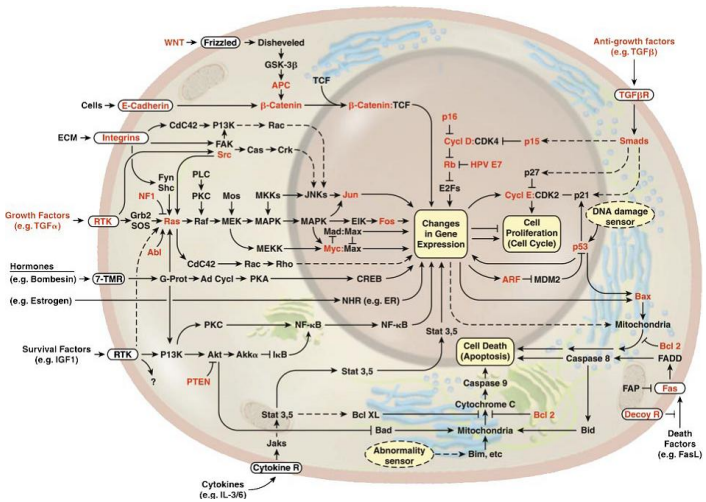
Queries: Email me with [CS735-2024] in subject line
akshayss@cse.iitb.ac.in

Goal

Formal Models for distributed and infinite-state systems





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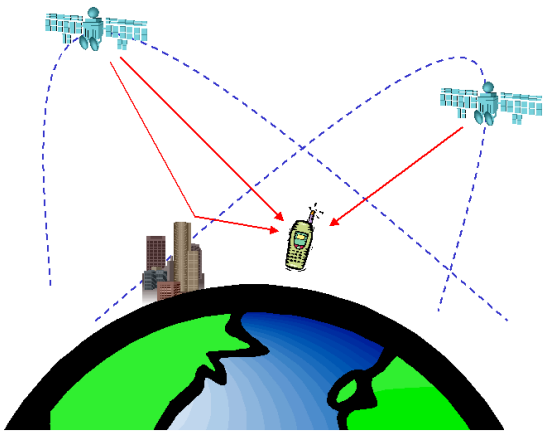
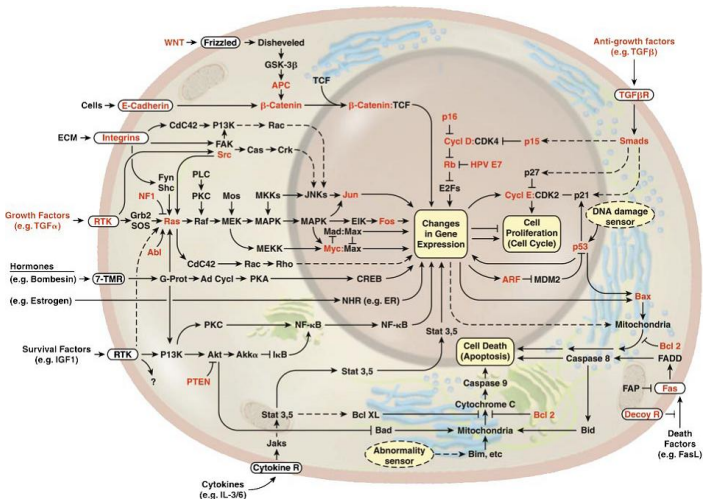
- Distributed: Concurrent, asynchronous, communicating,...





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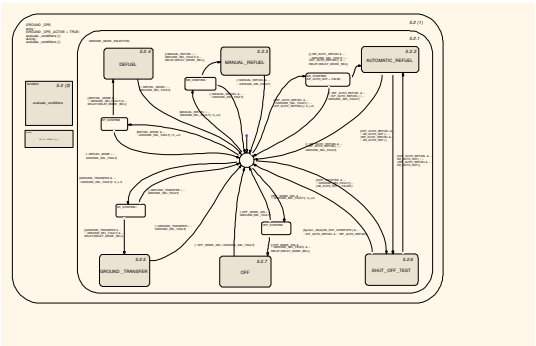

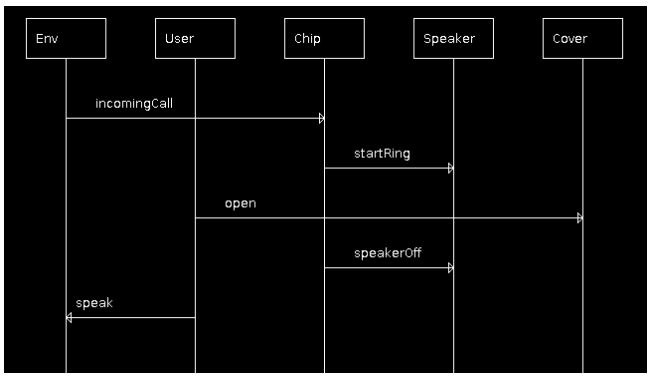

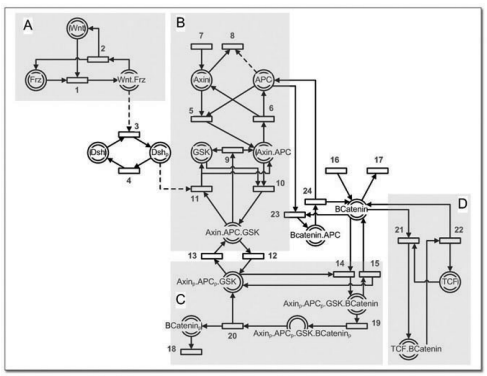

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Questions that we will tackle

- Analysis of such models
- Characterization, relations
- Underlying properties, generalizations

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Topics and models that we will cover in this course:

1. Petri nets
2. Well-structured transition systems
3. Distributed automata models and their behaviors
4. Advanced topics, extensions and applications

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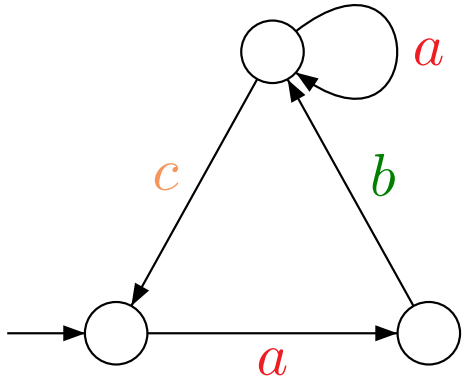
   - Concurrency in Programs
   - Concurrency and Quantities (Time/Probabilities)

Automata



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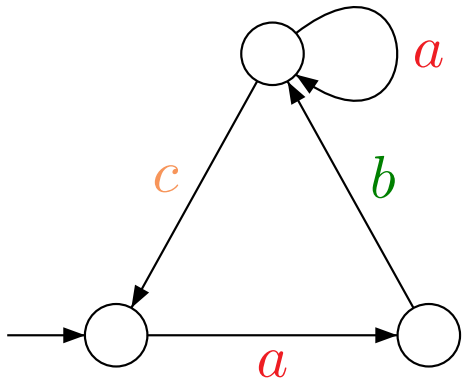

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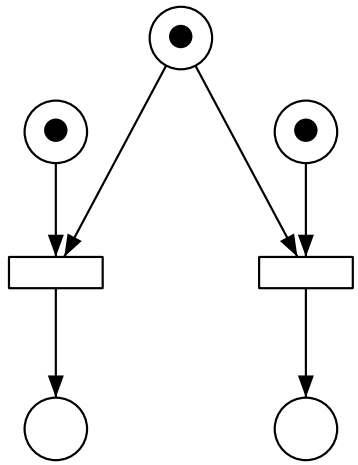
Questions

- How shall we distribute it?
- How shall we add concurrent behaviors?

Petri Nets

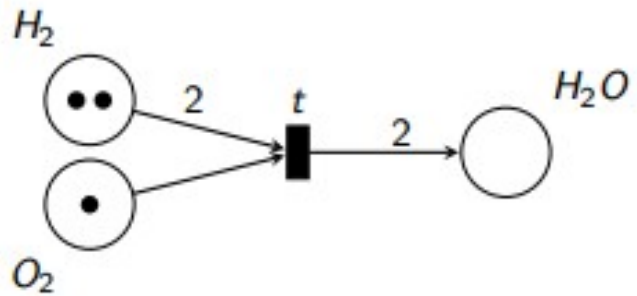


- An old model for distributed systems
  - invented by Carl Petri (-at the age of 13- in 1939? or '62)
  - to model resource consumption and so on...

Examples of Petri nets

- A chemical reaction: $2H_2 + O_2 \rightarrow 2H_2O$.
- A library
- A producer-consumer example
- A coffee machine

Examples of Petri nets



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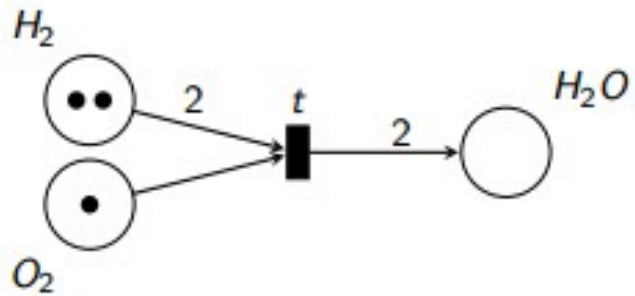

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Applications: Business process models, stochastic processes, biological networks and so on

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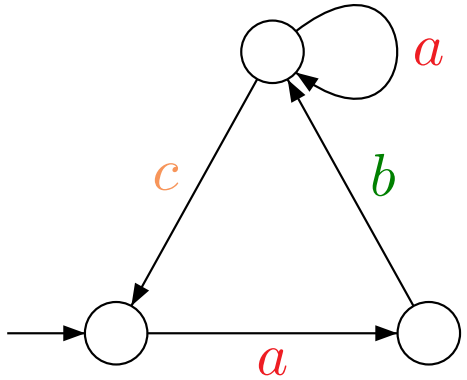

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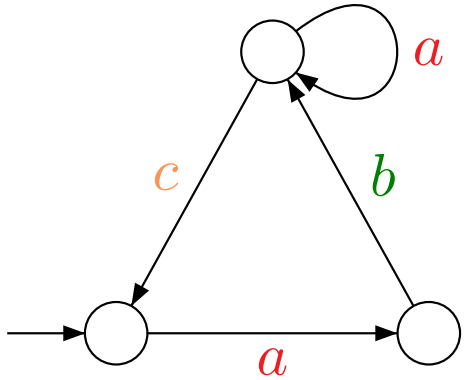

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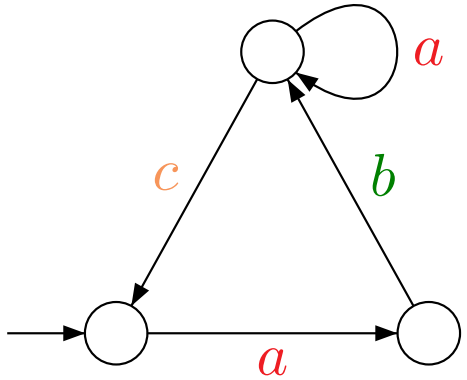

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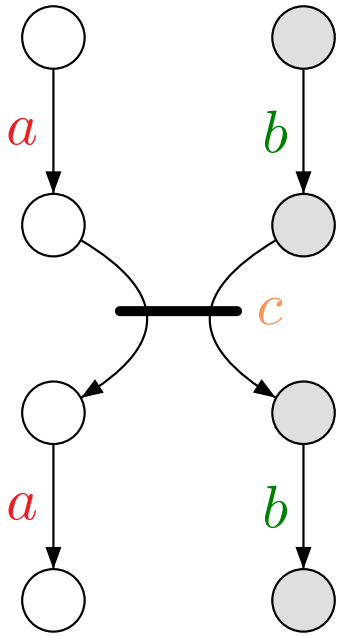
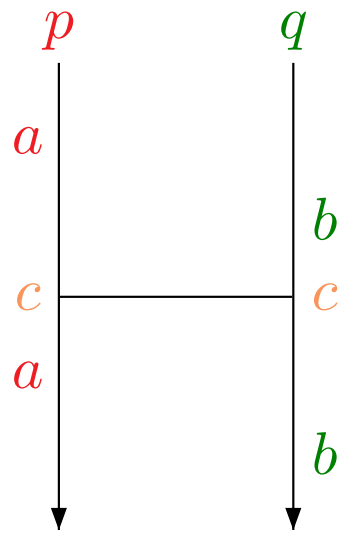
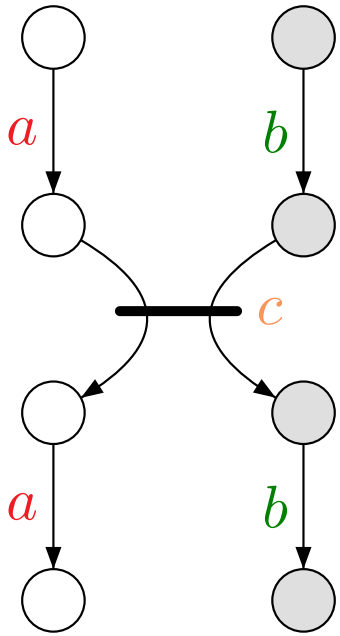
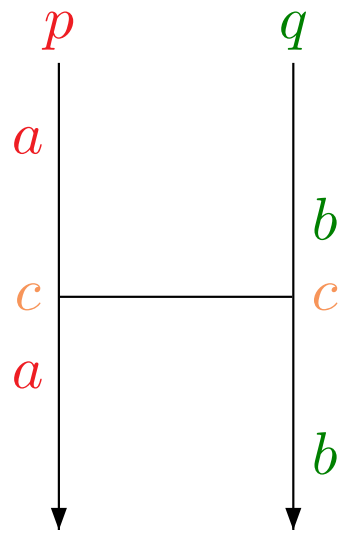




- Actions are distributed across processes (with sharing!)
- Some actions are shared, e.g., c is allowed only if both p and q move on c.

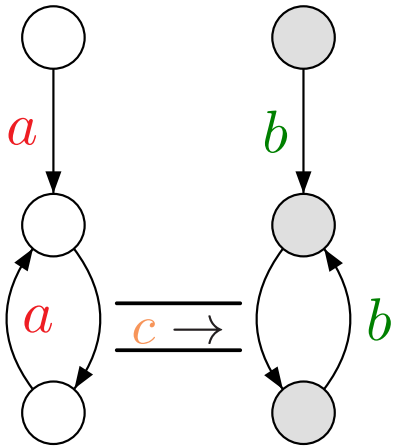
Asynchronous Automata

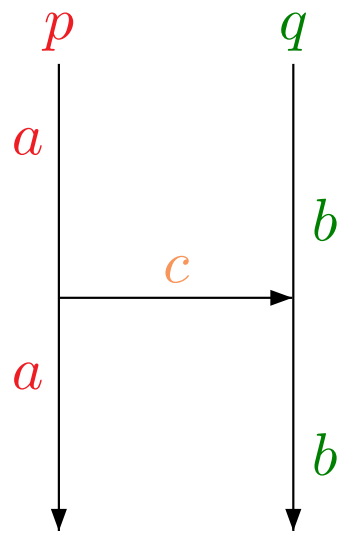




- What are the properties of languages accepted by such automata? E.g. above accepts $\{\underline{abcab}, bacab, bacba, abcba\}$.
- Given a language L, (when) can it be accepted by such an asynchronous automaton?

Message Passing Automata





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- We will consider decidability issues.

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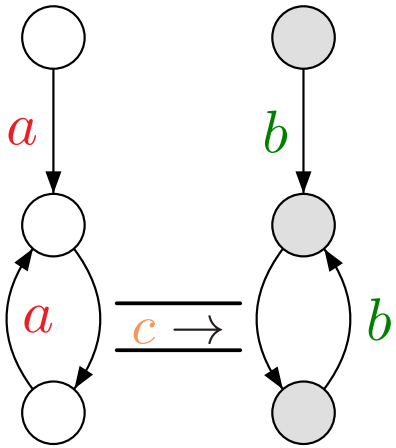

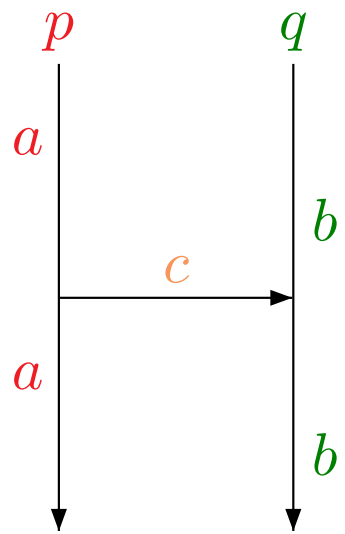

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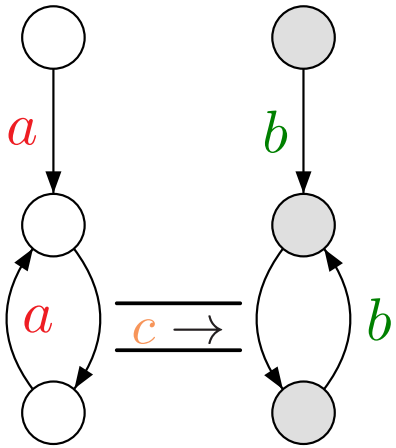

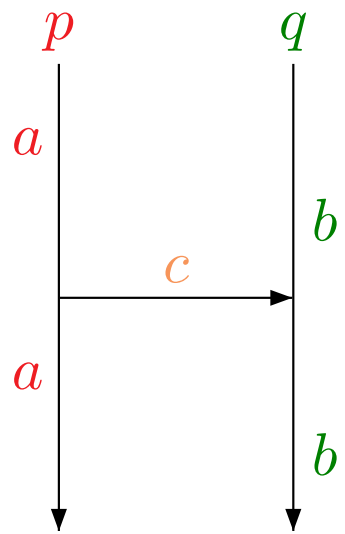

- In fact, this formalism is Turing powerful!
- We will consider decidability issues.
- (Surprising fact: If you are allowed to lose messages randomly then it is decidable!) These are called Lossy channel systems.

Applications to Concurrent programs

What are good formal models for concurrent programs?

- Automata or transition systems

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Does this capture reality of programs in today's world?

Modeling concurrent programs

Two issues

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Modeling concurrent programs

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- In the multi-processor world: memory access is no longer atomic!
- There is no non-determinism! How to avoid exploring runs

Leads to:

1. Weak memory models

2. Partial order reduction techniques

Modeling Quantitative Systems

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- Classical models and more.

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Another face of concurrency

- For decomposability of large systems!
- Reasoning and composing systems

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- Under-approximate verification
- Fixed-point approaches

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Pictures and Mathematics

- How do you write these objects mathematically?
- Why write them mathematically?

Some take-aways from this course

- Different formal models for distributed systems
- Mathematical formalisms that reason about (the infinite) behaviors of such systems.
- Techniques to automatically analyze such systems.
- How to use them and where they are applied.

Logistics

Evaluation (flexible/tentative... upto a point)

- Continuous evaluation - assignments/quizzes : 35%
- Exam (Midsem/Endsem): 35 %
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Course material, references will be posted at

- `http://www.cse.iitb.ac.in/~akshayss/teaching.html`
- Piazza will be set up soon