Is the Internet doomed to collapse?

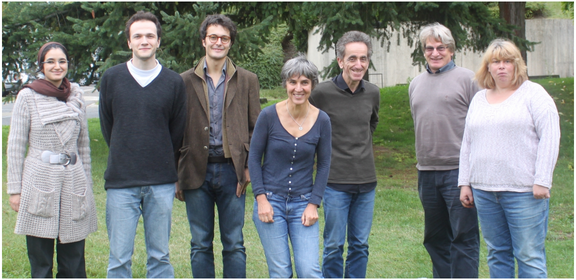
Mathieu Feuillet

Based on a joint work with T. Bonald and A. Proutière

Rocquencourt Junior seminar

15/05/2012

RAP Team



- Topic: Designing and analyzing network algorithms
- Tools: Mathematical modeling and probabilistic methods

Why mathematical modeling?

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Mathematical analysis allows to tackle the huge size and the different parameters... with some simplifications.

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What is the Internet?

Original goals

- Transmission of data from one computer to another

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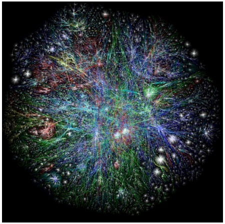

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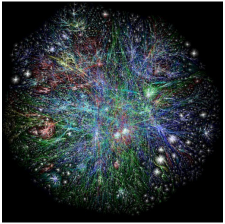


- Transmission of data from one computer to another

- Large network

- Distributed System

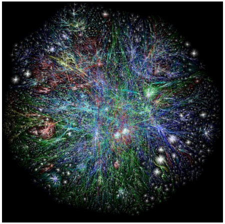
Original goals

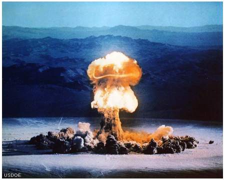
- Transmission of data from one computer to another

- Large network

- Distributed System

- Resist to the partial destruction





Packet switching

Data flow is cut into packets

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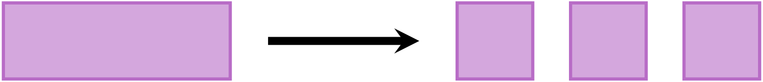

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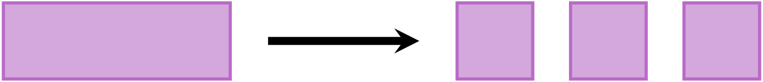

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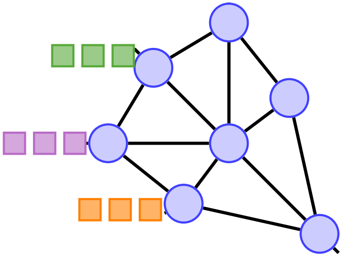

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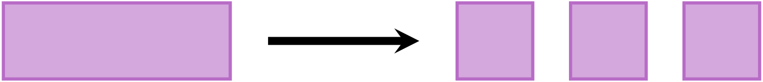

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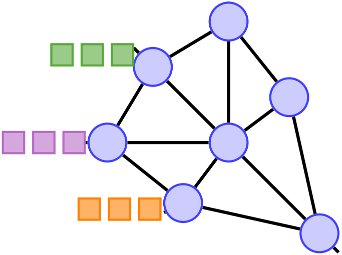

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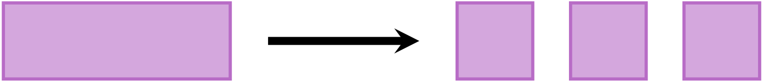

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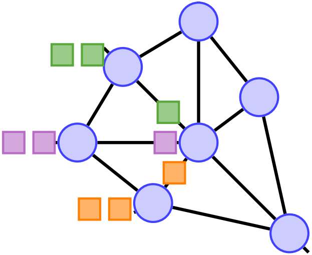

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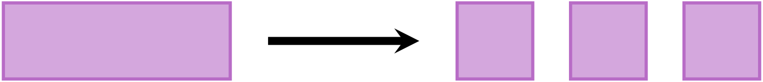

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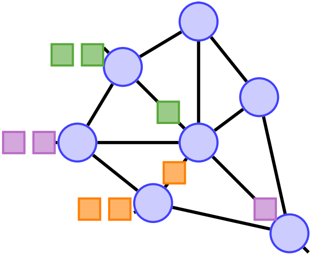

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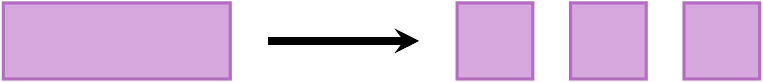

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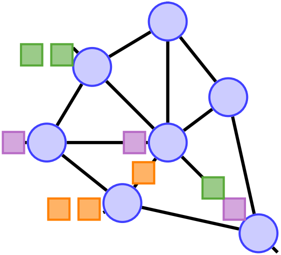

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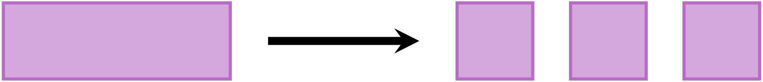

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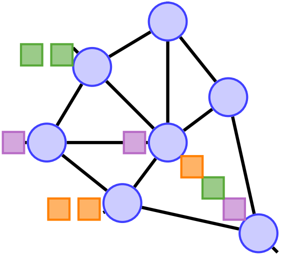

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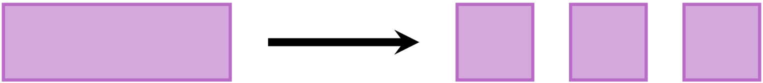

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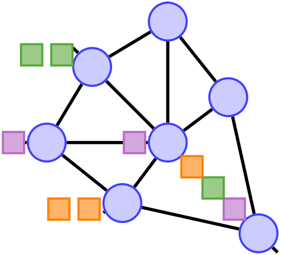
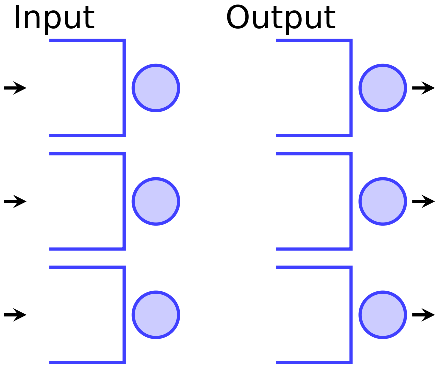


Internet:
routing and resource allocation

A router



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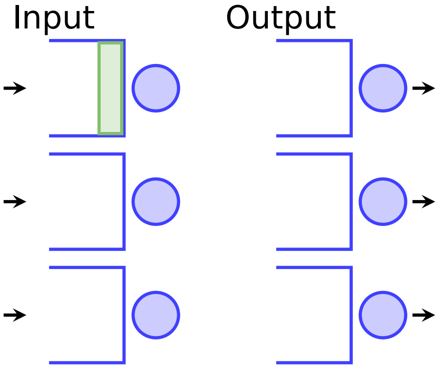

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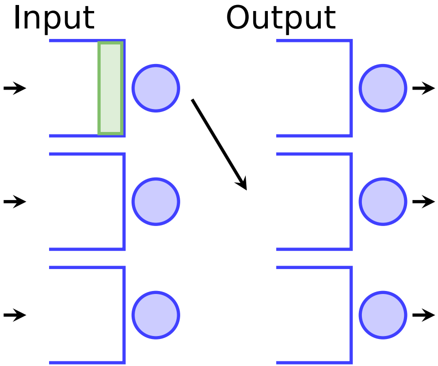

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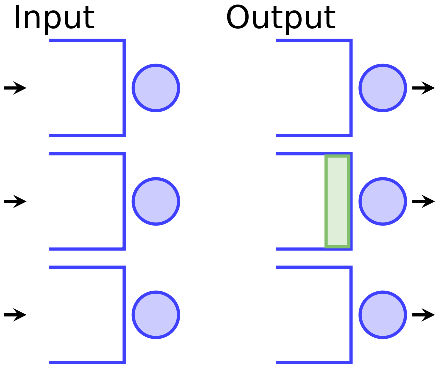

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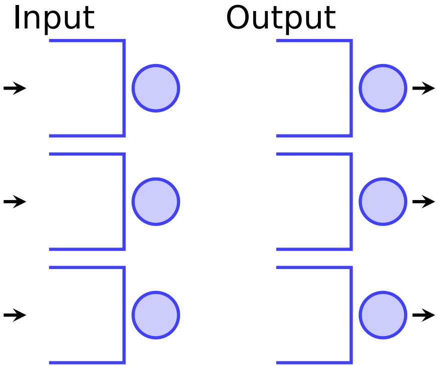

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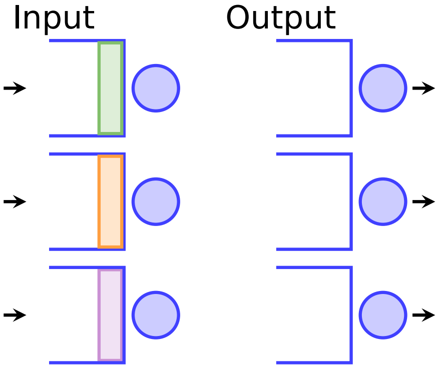

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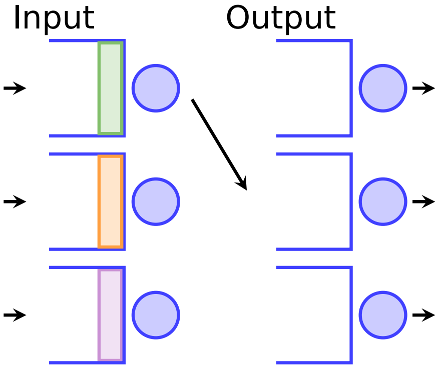

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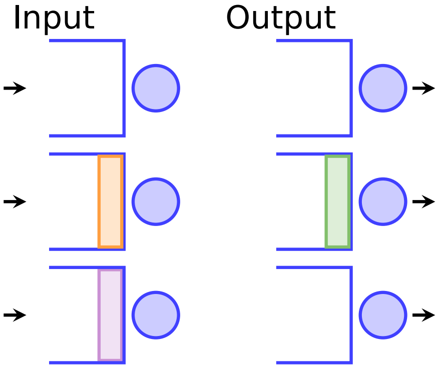

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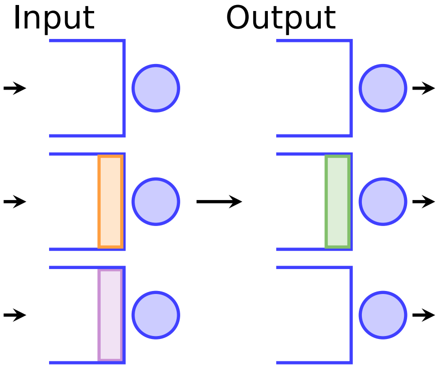

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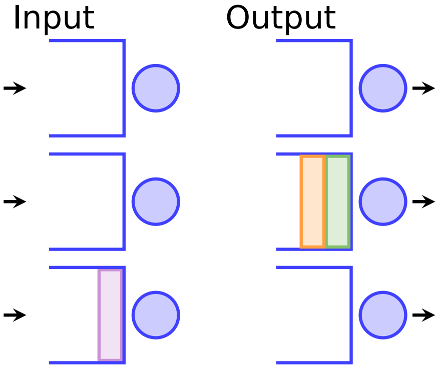

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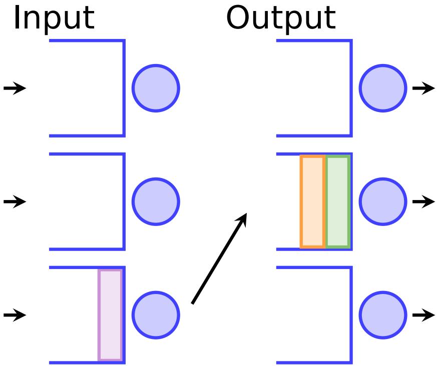

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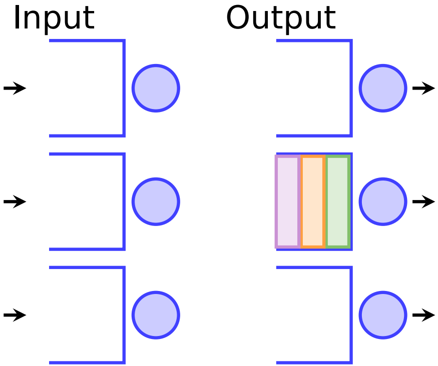

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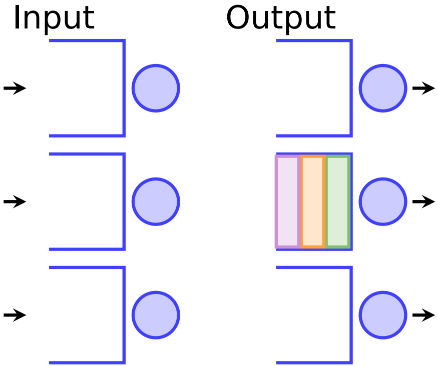

Input rate > Output rate:
congestion and packet drop

Packet switching and QoS

Drawbacks:

- No reliability: packets can be dropped on the route

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Application	Reliability	Delay	Bandwidth
File transfer	++	- -	+-
Web access	++	+-	+-
Video on Demand	- -	- -	++
Telephony	- -	++	- -

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Transport Control Protocol
(TCP)

Principles

Reliability:

- An acknowledgement for each packet.
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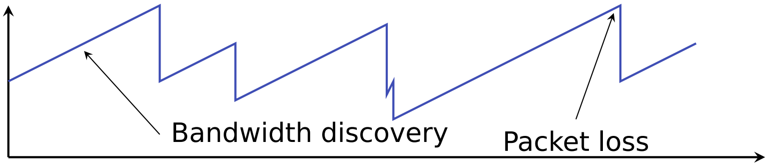
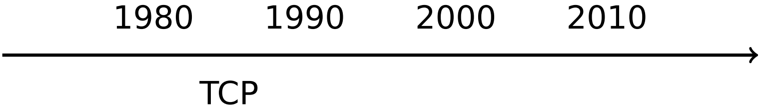
Bandwidth allocation and congestion control:

- No loss detected: Sending rate increased linearly.
- Losses detected: Sending rate divided by a factor.



Problem solved?



Problem solved?

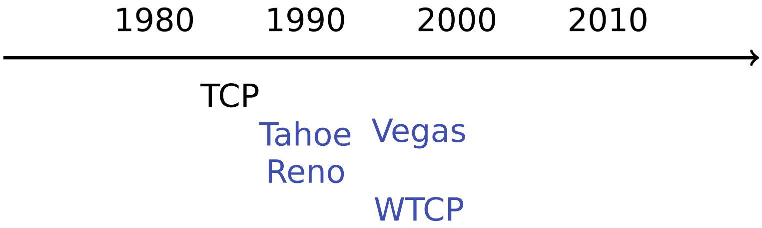
1980 1990 2000 2010

TCP

Tahoe

Reno

Problem solved?



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Why so many versions?

TCP issues

- TCP over wireless

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- Losses in burst

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TCP-friendliness

Users are required to cooperate and be well-behaved

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TCP-friendliness

Users are required to cooperate and be well-behaved

What if computers stop being polite?

No congestion control: the Law of the Jungle

Principles

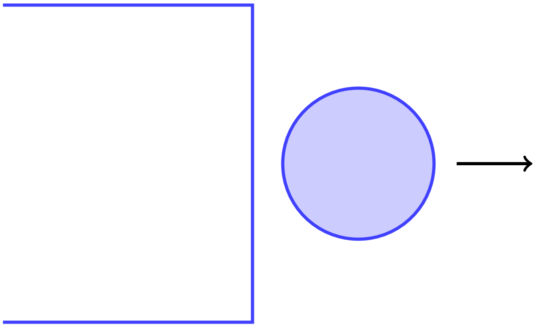
- Use source coding (digital fountains) to protect against losses

- Send data in the network at maximum rate (worst case)

- Bandwidth allocation is determined by dropping policies in routers

Dropping policies

Tail Dropping



When the queue is full, drop any new packet

Dropping policies

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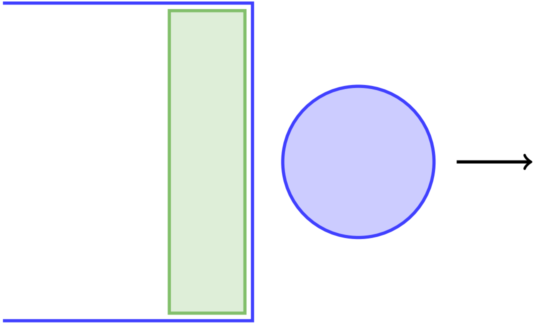

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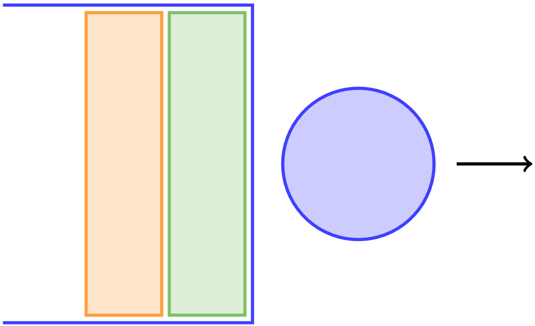

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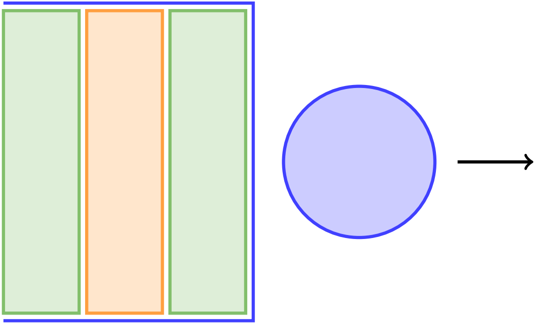

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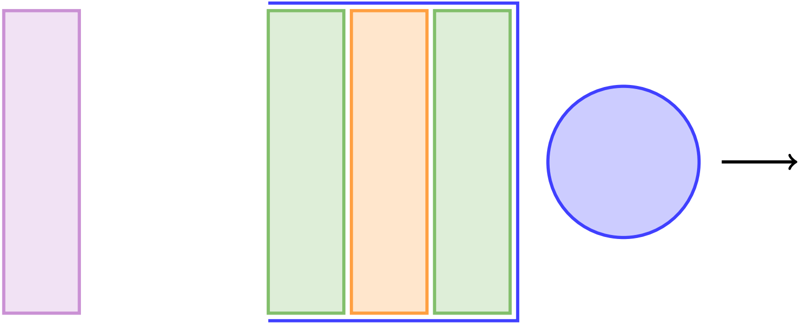

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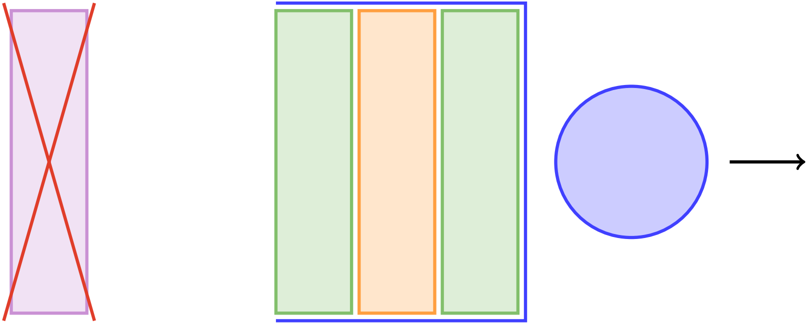

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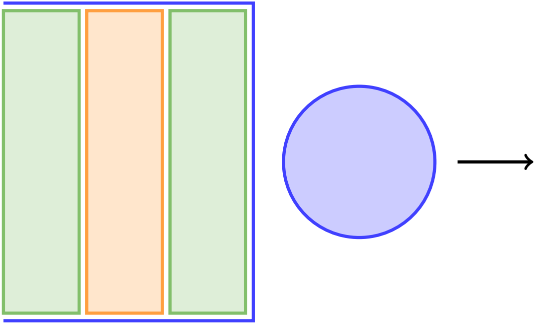

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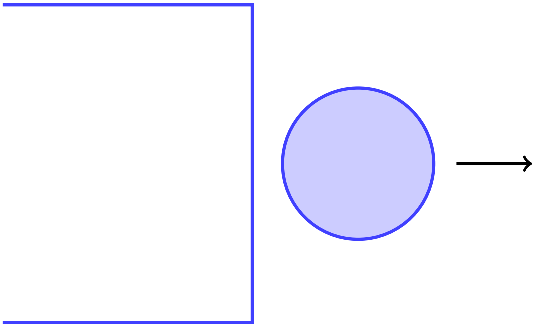

When the queue is full, drop from the biggest flow

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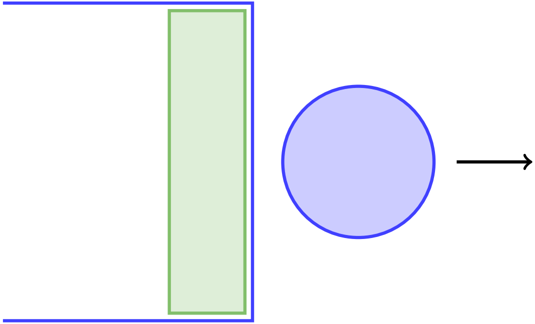

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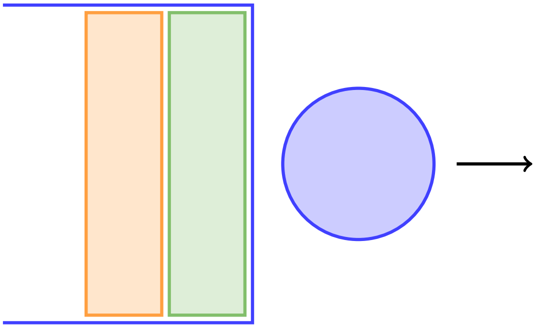

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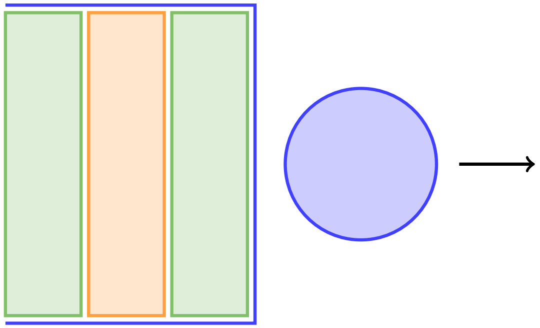

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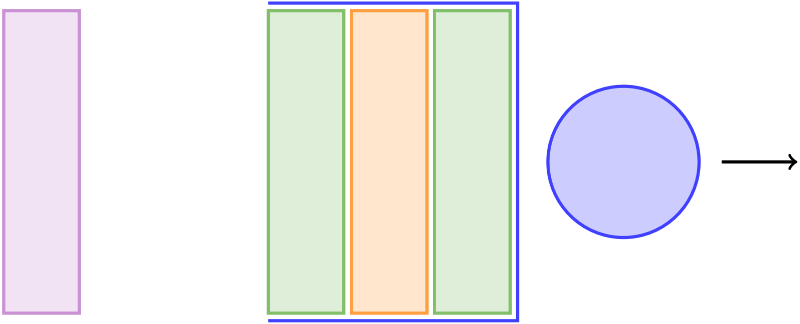

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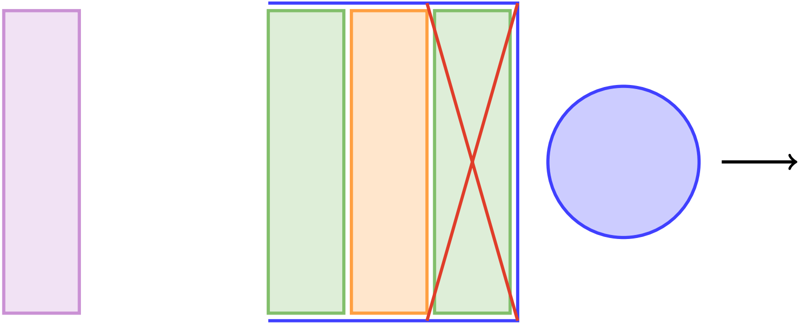

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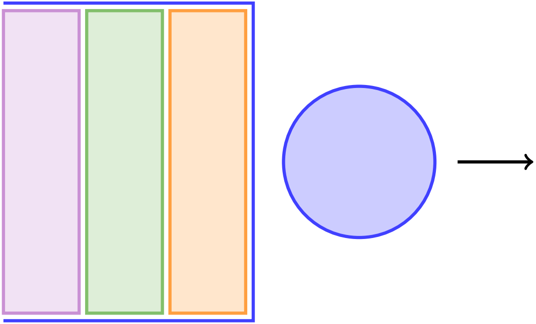
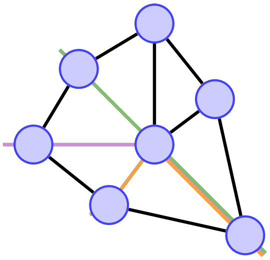


When the queue is full, drop from the biggest flow

Fluid model

Mathematical model:

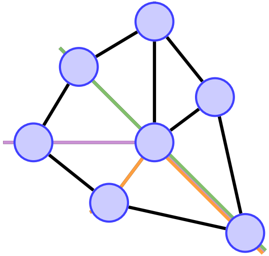
- Packets replaced by fluid of data
- Flows arrive in the network according to Poisson processes
- Each flow has an exponentially distributed size



With the dropping policy, it defines a Markov process.

Fluid model

Stability: The network is stable if each flow is served in finite time.



Maximal stability condition: At each link, the offered traffic is less than the capacity of the link

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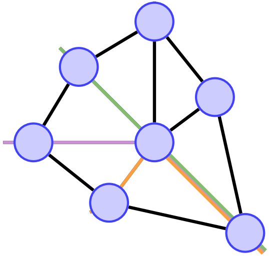
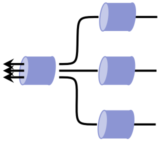
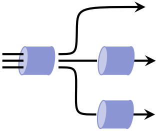


When is the network stable?

Tail Dropping





Maximal stability condition!

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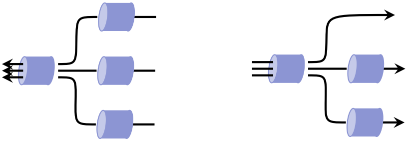

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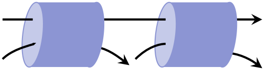
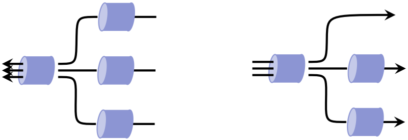
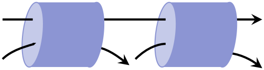


Suboptimal stability condition!

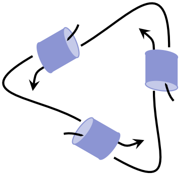
Tail Dropping



Maximal stability condition!



Suboptimal stability condition!



Never stable! Congestion collapse!

Fair Dropping

Theorem: Any network is stable under the maximal stability condition.

Source coding and Fair dropping are sufficient to ensure an efficient use of the network resources independently of users!

Technical corner

Main simplification: Remove all randomness except arrivals and departure

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Stability of network $\Leftrightarrow$ Ergodicity of Markov process

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Proofs based on:

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Proofs based on:

- Stochastic domination

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Stability of network $\Leftrightarrow$ Ergodicity of Markov process

Proofs based on:

- Stochastic domination
- Lyapunov functions
- Scaling methods (fluid limits)

Conclusion

- An example of mathematical analysis of network performance

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- Will the Internet collapse?

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- Will the Internet collapse?
  - With Fair Dropping, no
  - With Tail Dropping, possibly...

Thank you!