

NETWORKING THEORY: A PERSONAL PERSPECTIVE

JEAN WALRAND

9/7/2018

HUMM...

- I HAVE 1 MINUTE AND 15 SECONDS PER YEAR ...
- THERE IS NOTHING I CAN SAY YOU DON'T KNOW ...
- THIS IS AN IMPOSSIBLE TALK ...
- TOO LATE TO CALL IN SICK?
- DAMN THE ORGANIZERS WHO INSISTED THAT I GIVE THIS TALK!
- I THOUGHT I HAD RETIRED

“NETWORKING THEORY IS USELESS”

MR. -----, -----, CISCO CERTIFIED ENGINEER, 7/1995

“WE HAVE ENOUGH THEORY FOR
THE NEXT 15 YEARS”

PROF. -----, -----, 9/1987

“THEORY?: YOU CHANGE THE
ASSUMPTIONS, YOU GET NEW
CONCLUSIONS!”

DR. ----, -----, 11/2012

“TCP: SLOW DOWN WHEN CONGESTED,
THAT’S ALL THERE IS TO IT!”

DR. ---, ---- 10/2011

“NETWORKING: THE PROBLEM IS SOLVED!”

PROF. -----, ----- 5/2012

INDEED, MOST OF NETWORKING DOES NOT REQUIRE ANY THEORY

- PACKET SWITCHING
- LAYERS, INTERNETWORKING
- SHORTEST PATH
- CSMA
- MPLS, VLAN
- SNMP, RMON, SDN, NFV

INNOVATIVE, DISRUPTIVE, BUT SIMPLE IDEAS

SO THEN, WHAT IS THE USEFULNESS OF
NETWORKING THEORY?

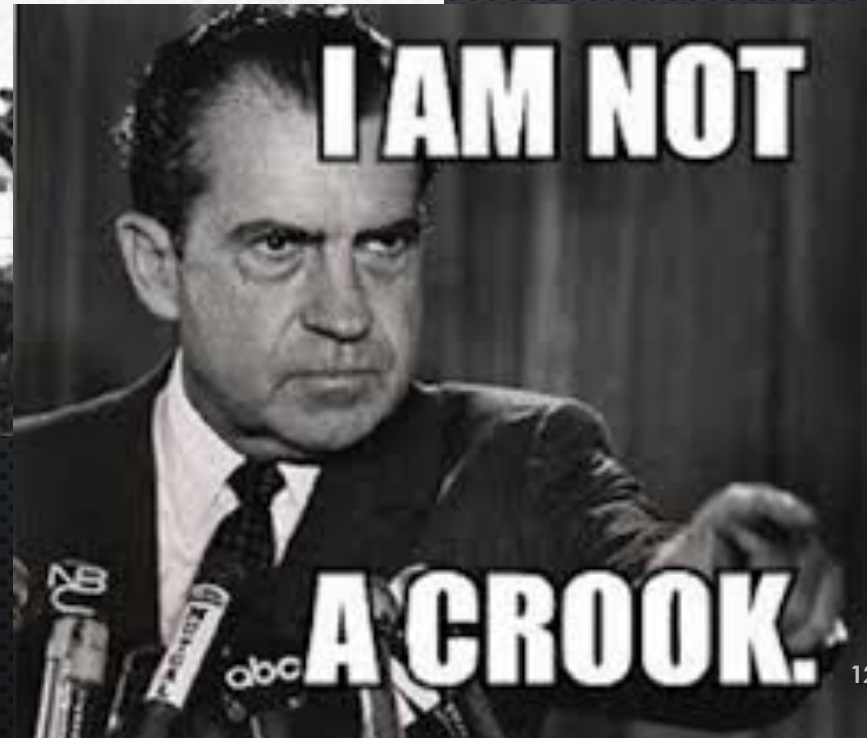
HISTORICAL CONTEXT: BERKELEY IN ~~1975~~ ~~1960~~ 1875



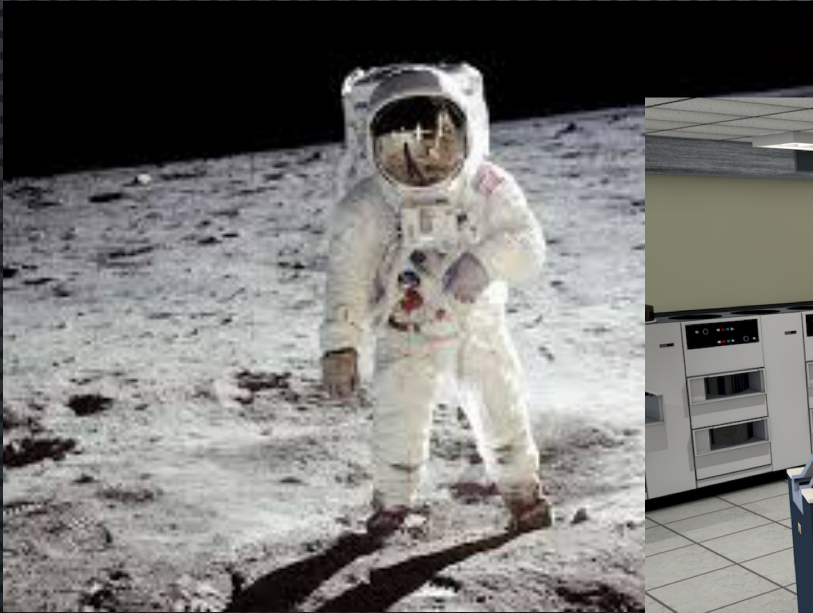
HISTORICAL CONTEXT: 1975



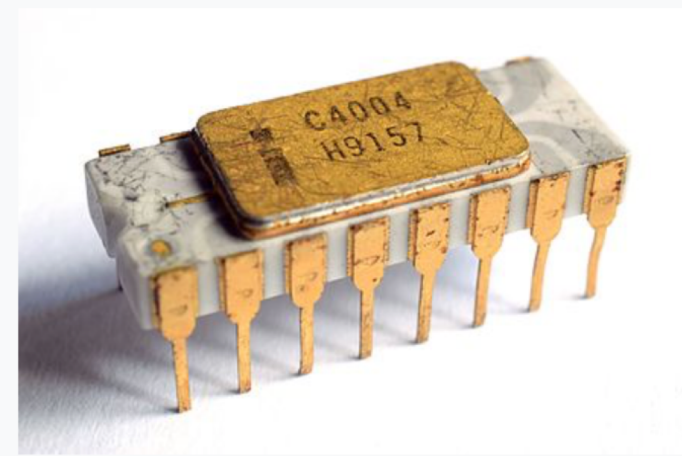
HISTORICAL CONTEXT: 1975



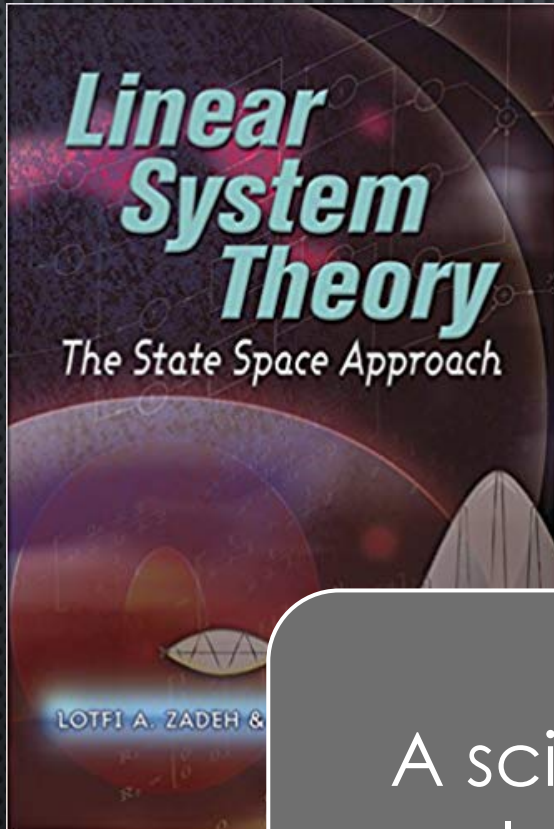
HISTORICAL CONTEXT: 1975



Intel 4004



HISTORICAL CONTEXT: BERKELEY 1975 – MORE DIRECTLY RELEVANT:



1976



SIAM Journal on Control, 13(5), 1022–1061. (40 pages)

Martingales on Jump Processes. II: Applications

R. Boel, P. Varaiya, and E. Wong

<https://doi.org/10.1137/0313064>

SIAM J. CONTROL
Vol. 13, No. 5, August 1975

MARTINGALES ON JUMP PROCESSES. II: APPLICATIONS*

R. BOEL, P. VARAIYA AND E. WONG†

1. Introduction and summary. This paper is concerned with applying the theory of martingales of jump processes to various problems arising in communication and control. It parallels the approaches which have been recently discovered in dealing with similar problems where the underlying stochastic process is Brownian motion. Indeed these approaches have recently been extended, starting with the work of Snyder [14], [16], [30] and Brémaud [6], [28], to the case of the Poisson process and its transformations. The paper can then be seen as a natural generalization to this recent work.

1975

A scientific approach to the analysis and design of systems

WHY THEORY IN NETWORKING?

- MAJOR NEW CHALLENGES
- THEORY IS NECESSARY

INNOVATION PROCESS:

Caricature → Scheme → Design



INNOVATION PROCESS:

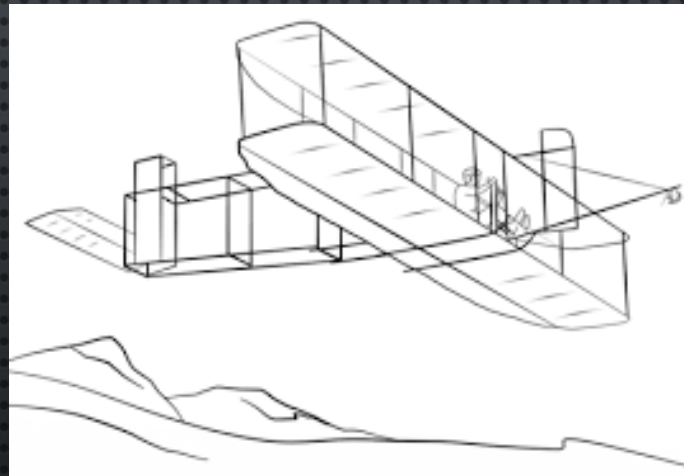
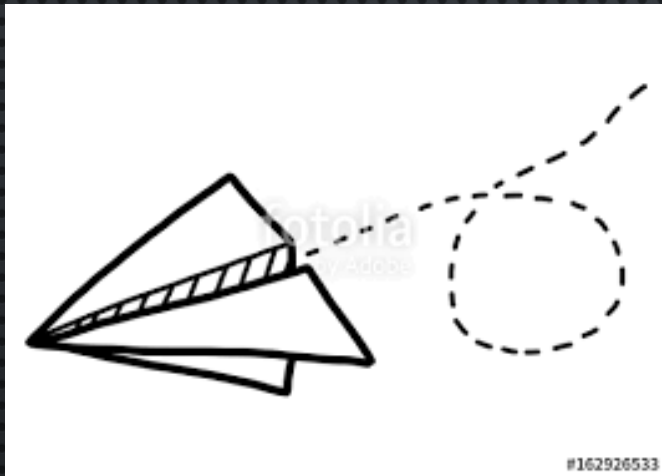
Caricature



Scheme



Design



INNOVATION PROCESS:

Caricature



Scheme



Design



INNOVATION PROCESS:

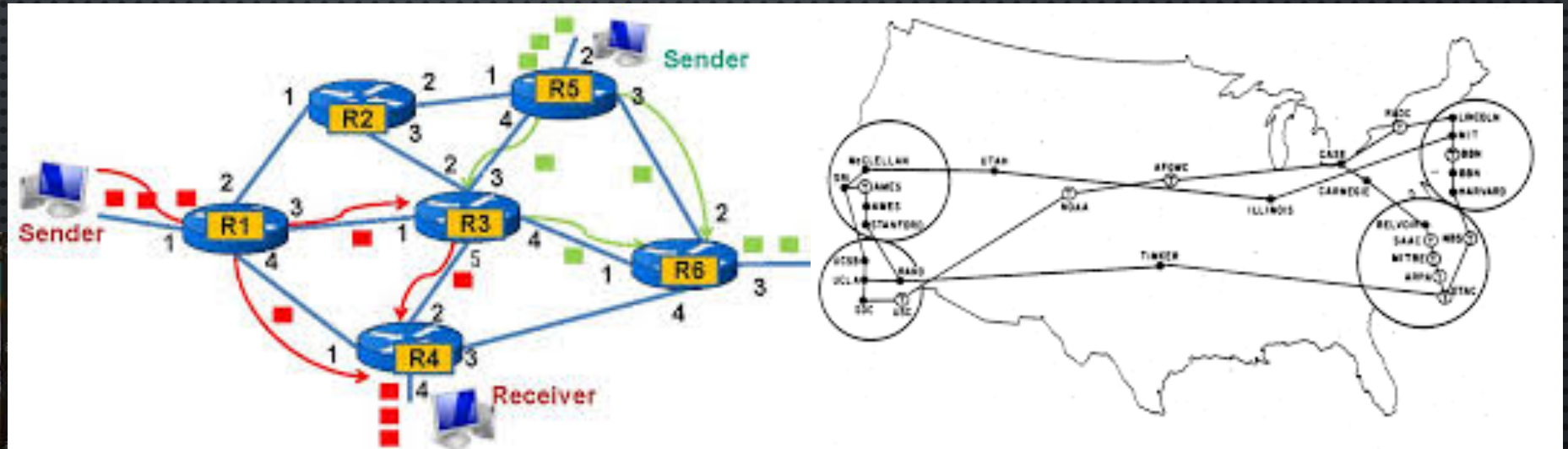
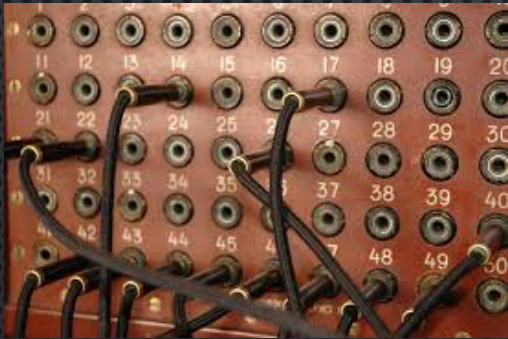
Caricature



Scheme



Design



alamy stock photo

INNOVATION PROCESS:

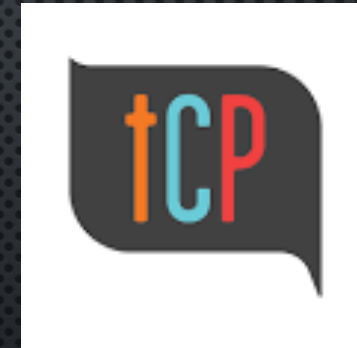
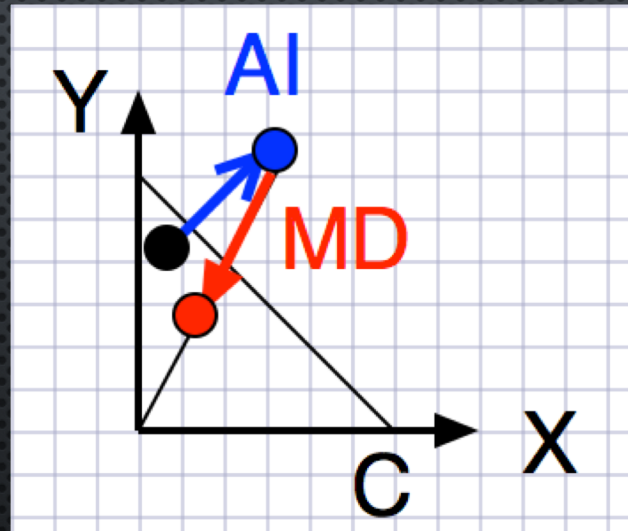
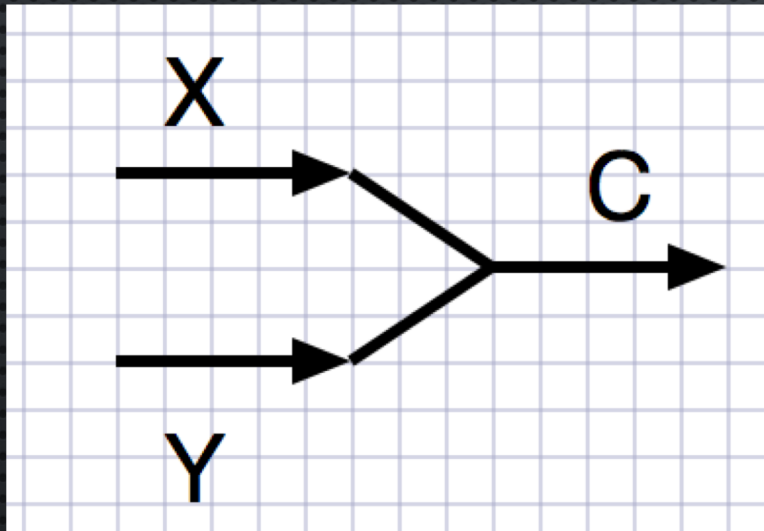
Caricature



Scheme



Design



INNOVATION PROCESS:

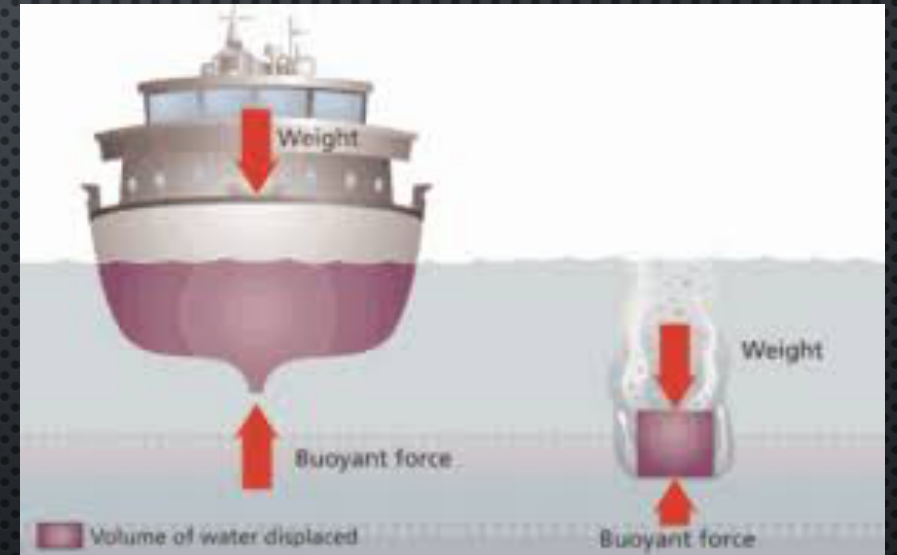
Caricature



Scheme



Design



INNOVATION PROCESS:

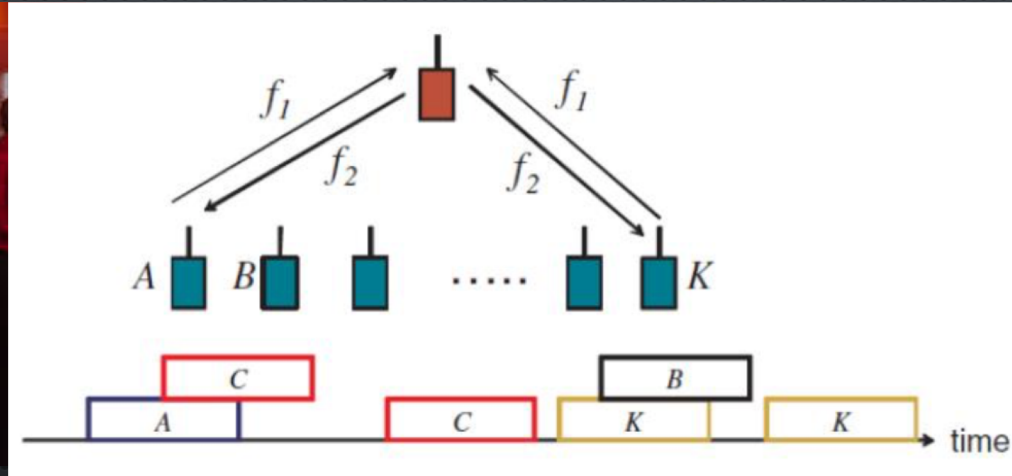
Caricature



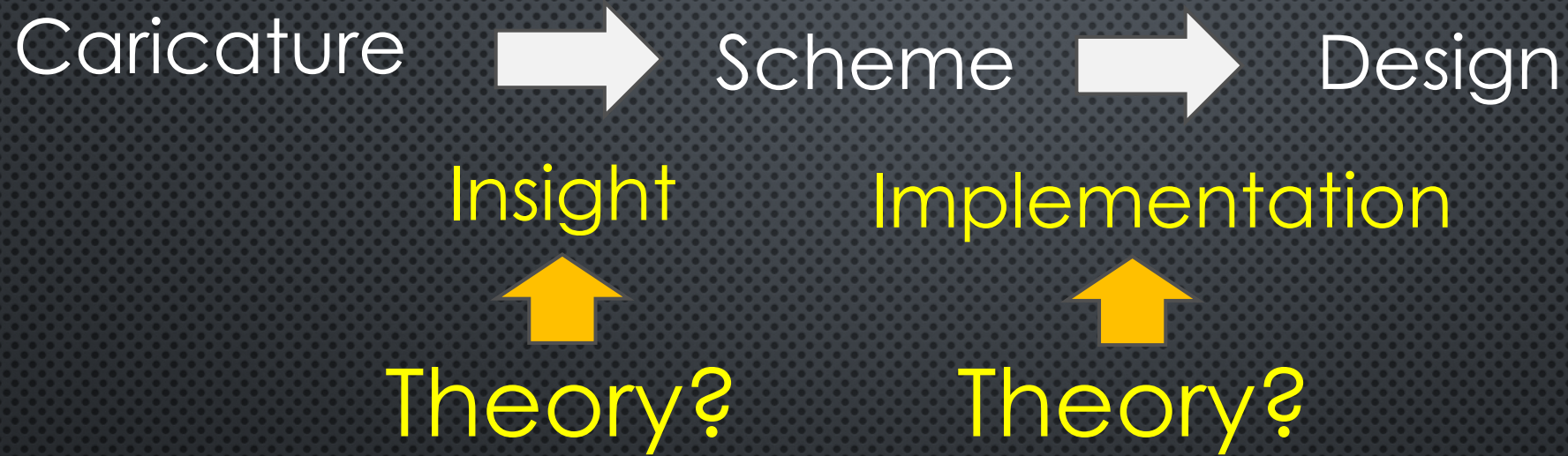
Scheme



Design



INNOVATION PROCESS:



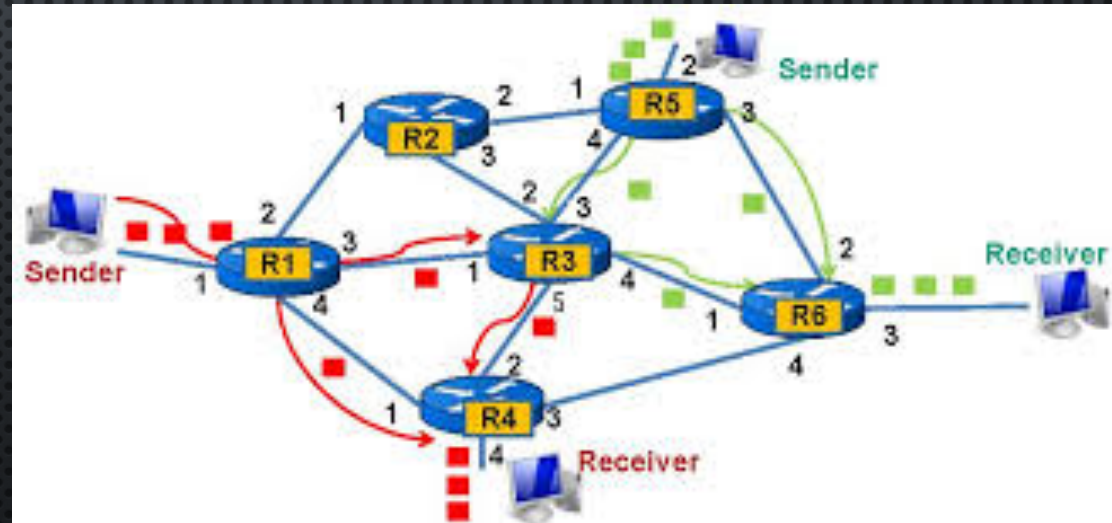
All possibilities exist:

- No, No
- No, Yes
- Yes, Yes
- Yes, No

INNOVATION PROCESS:

Caricature  Scheme  Design

No Theory



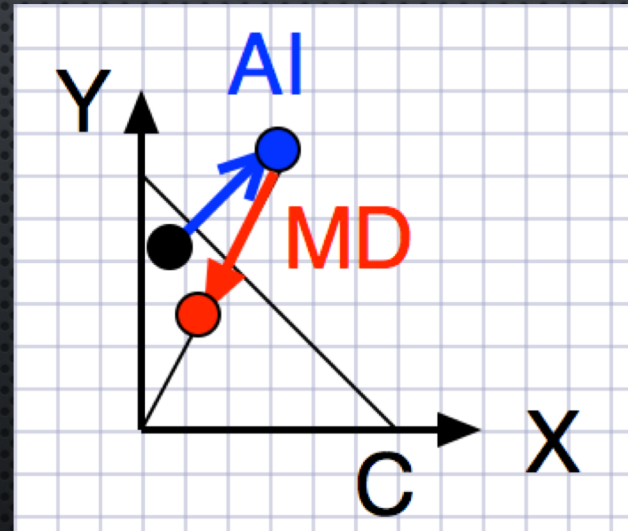
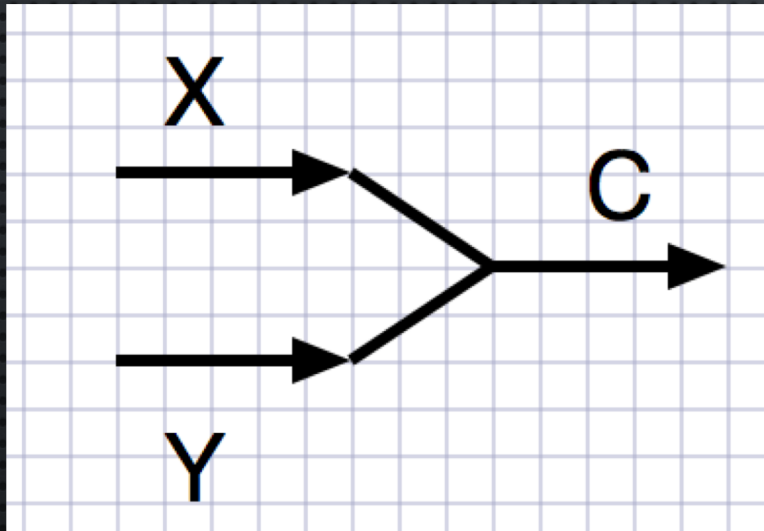
INNOVATION PROCESS:



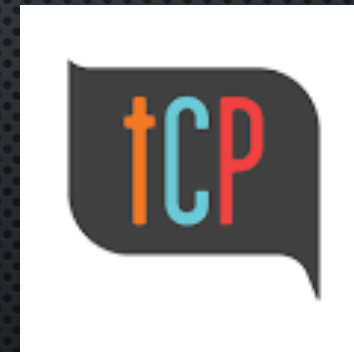
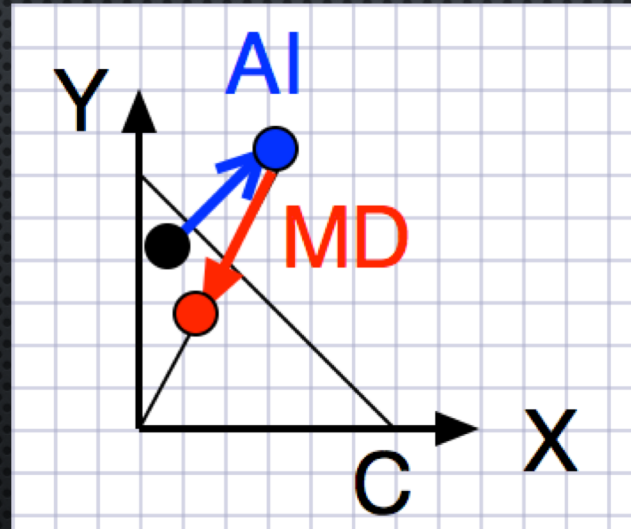
INNOVATION PROCESS:

Caricature  Scheme  Design

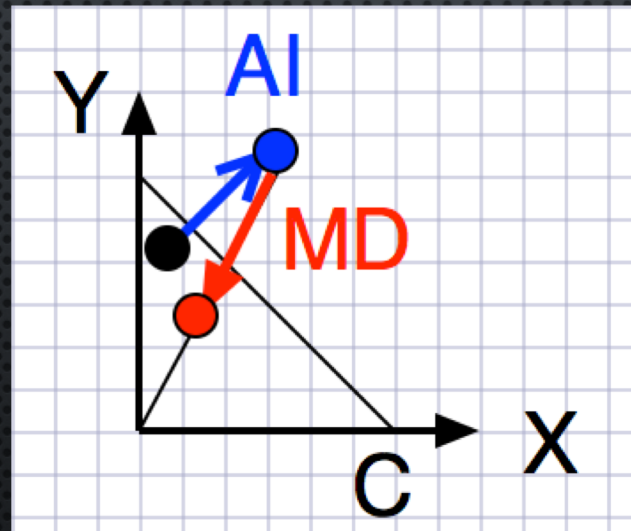
Easy Theory



INNOVATION PROCESS:



INNOVATION PROCESS:



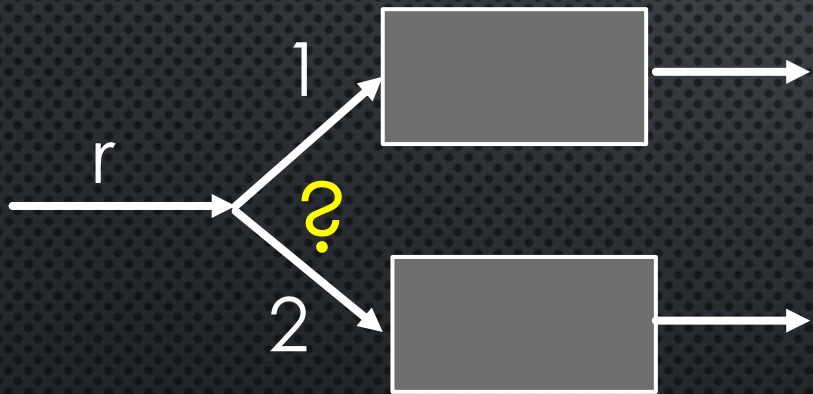
Proportional Fairness
 α -Fair TCP
Fast TCP
Backpressure
Regulated TCP

F. Kelly et al., S. Low, J. Mo, Modiano, Neely, Longbo Huang,^{28/TBD}
Srikant, Shakkotai, Ying, Alizadeh, Prabhakar, McKeown, ...

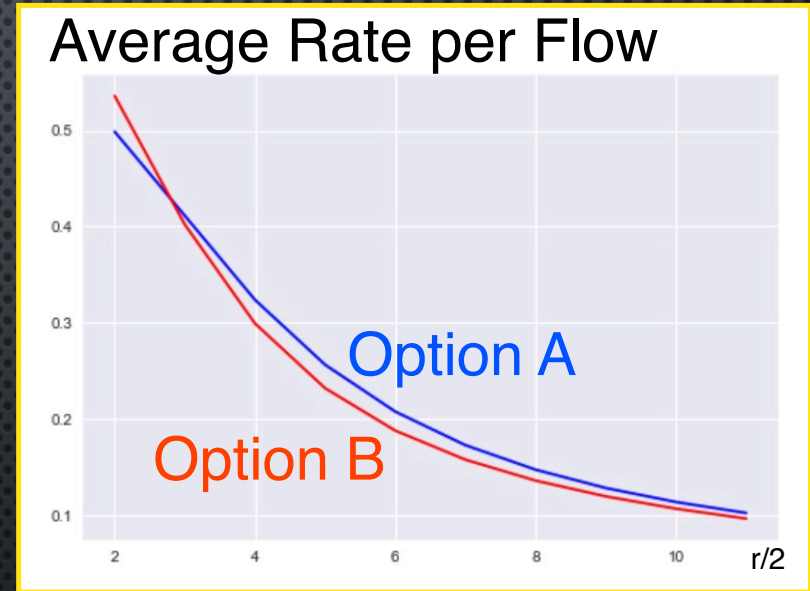
INNOVATION PROCESS:

Caricature  Scheme  Design

Theory



- A: Route flow randomly
- B: Route flow to least busy path

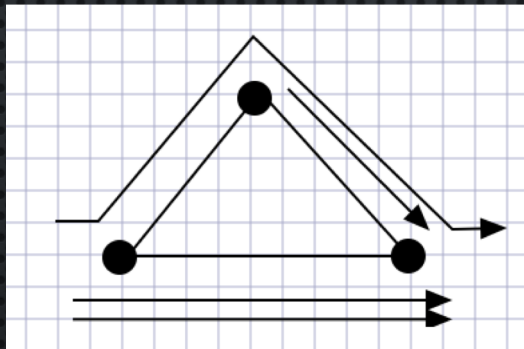


Related: Ephremides, Varaiya, Hajek, Rosberg, Gallager, Bertsekas, Gafni, Teneketsis et al., ...

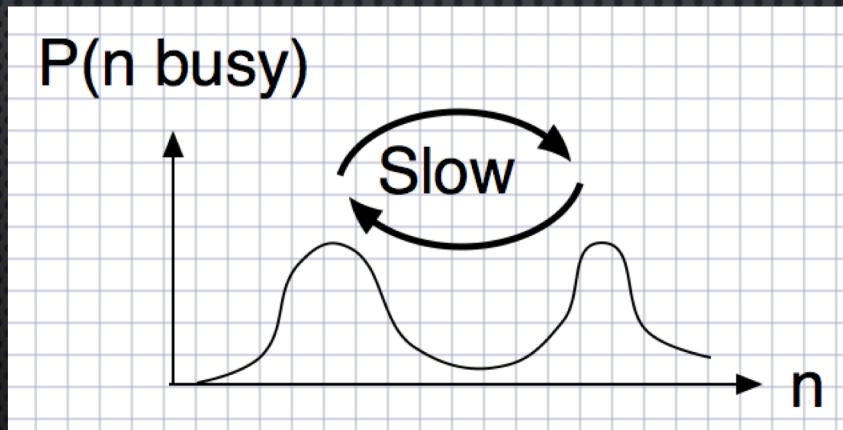
INNOVATION PROCESS:

Caricature  Scheme  Design

Theory



Alternate
Routing



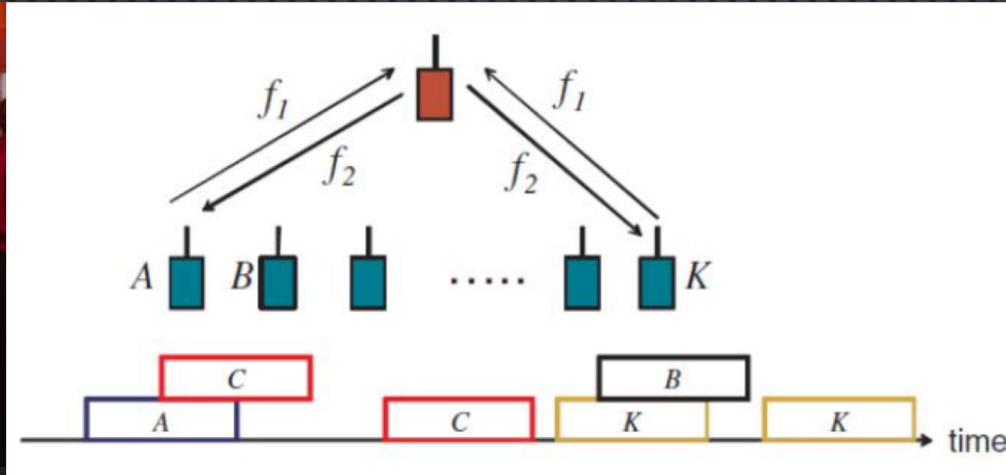
Metastability

Trunk
Reservation

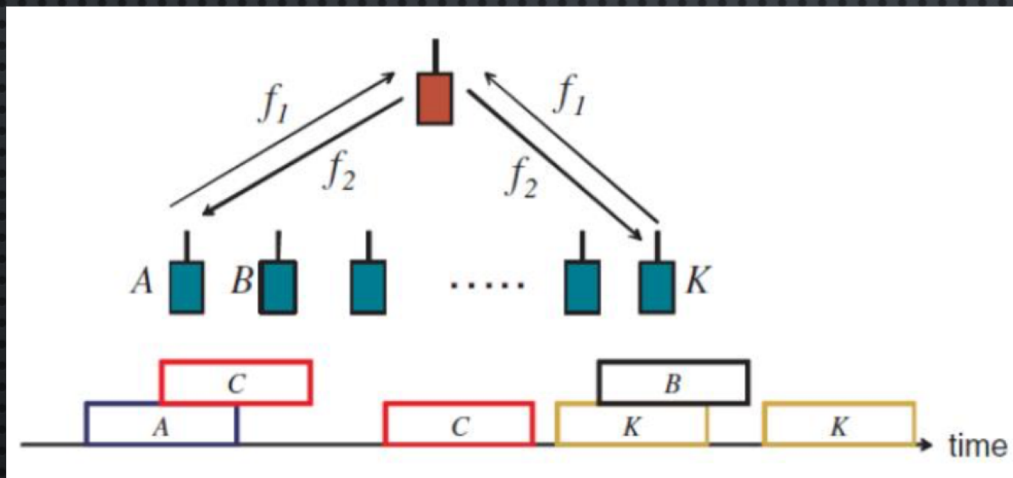
INNOVATION PROCESS:

Caricature  Scheme  Design

Easy Theory



INNOVATION PROCESS:

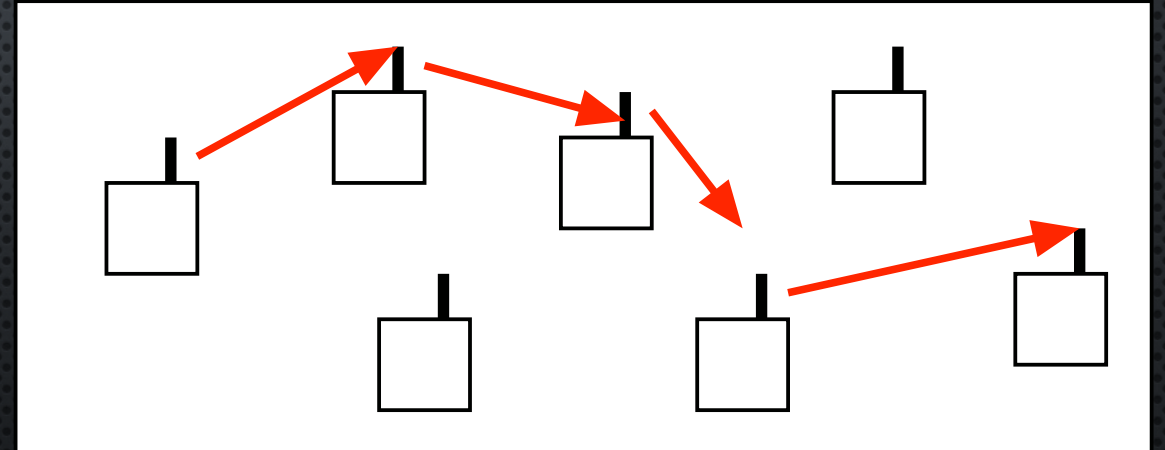
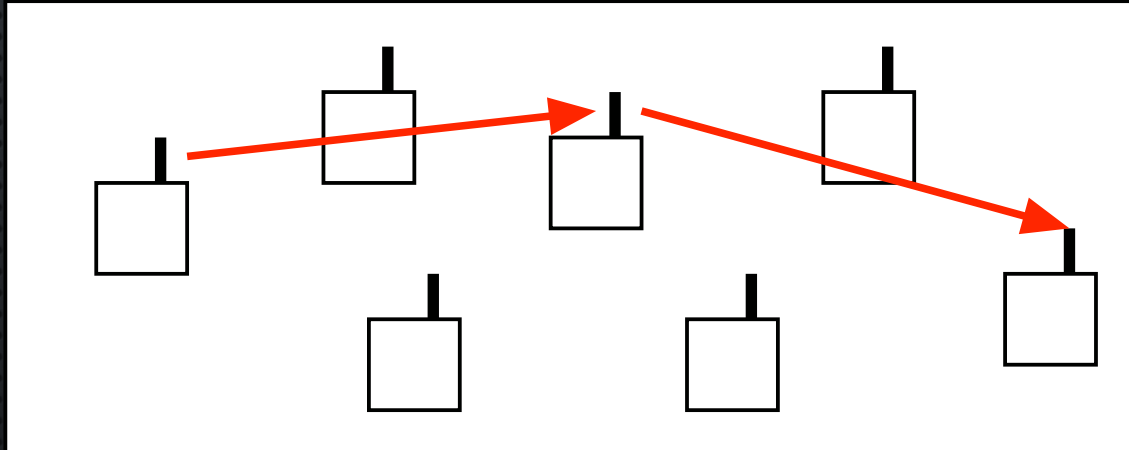


Q-CSMA

INNOVATION PROCESS:

Caricature  Scheme  Design

Theory



INNOVATION PROCESS:



Theory



Braess'
Paradox

Price of
Anarchy

Tardos, Roughgarden, Tsitsiklis,
Johari, Prabhakar...

INNOVATION PROCESS:

Caricature  Scheme  Design

No Theory



Cheap, but
crowded



First class, comfort
because of price

A. Odlyzko

35/TBD

INNOVATION PROCESS:



Easy Theory



Positive Externality often results in free-riding

INNOVATION PROCESS:



Sub-optimum investments in network security
[Anantharam, Libin Jiang, Schwartz, Shetty](#)

Security as a game:
[Basar, Baras, Musacchio, Anantharam & Gueye](#)

INNOVATION PROCESS:

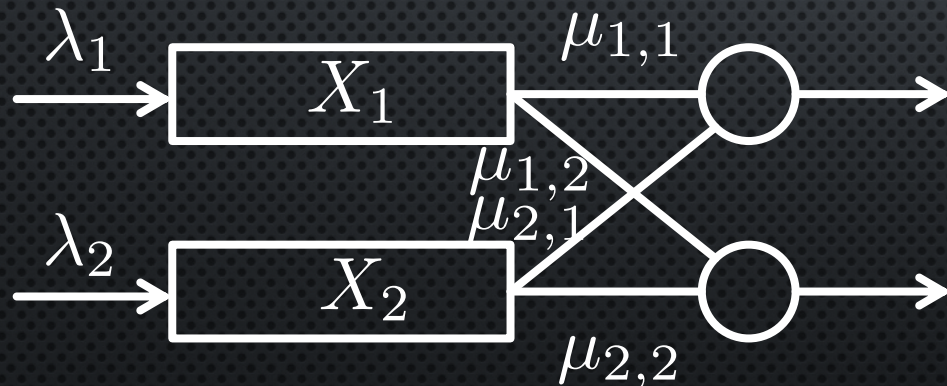


Theory

No Theory

MWM

iSLIP



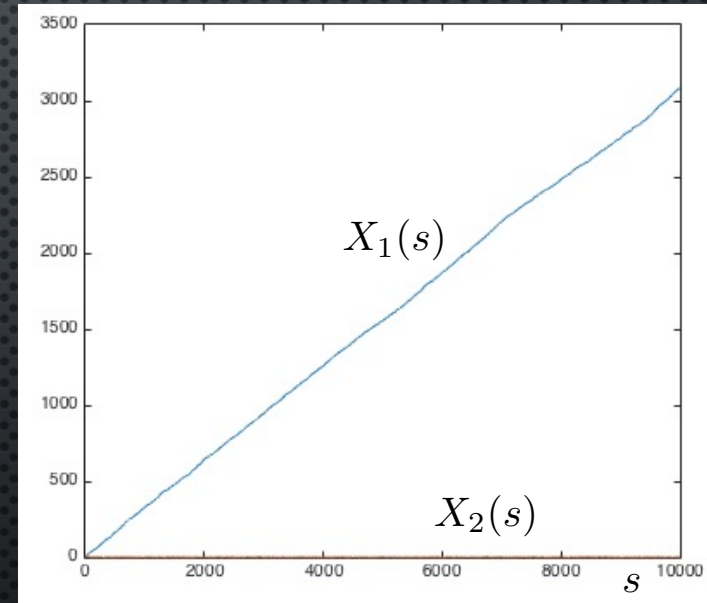
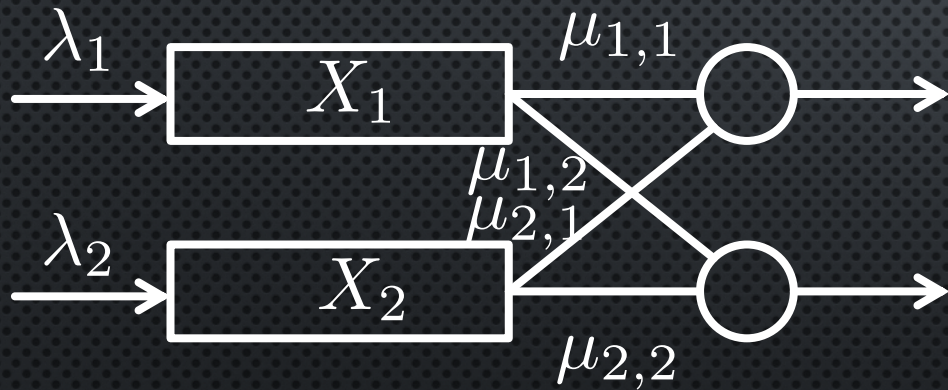
Ephremides, Tassiulas

McKeown

INNOVATION PROCESS:

Caricature \rightarrow Scheme \rightarrow Design

Theory



Rates unknown

Certainty equivalence: unstable

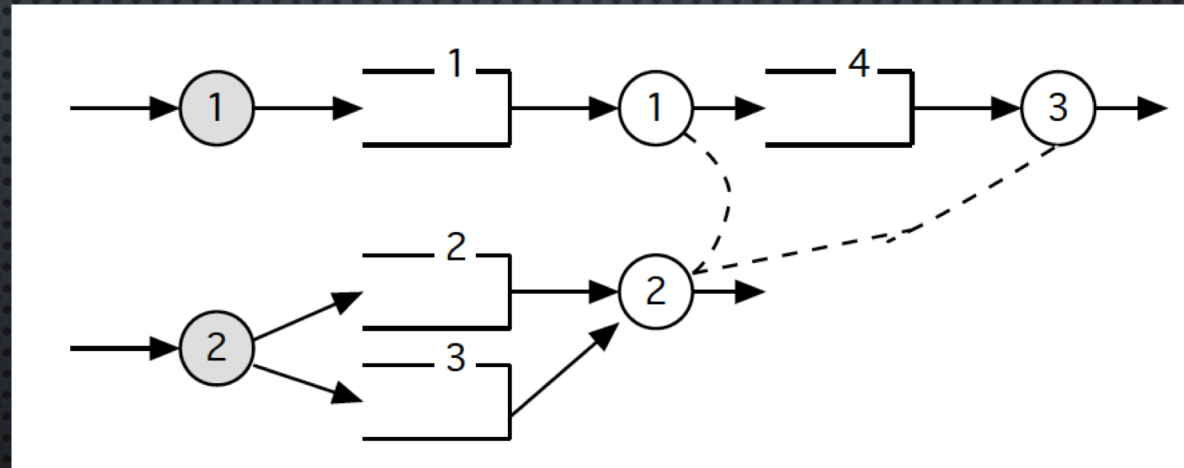
Pedarsani, Zhong; Gittins, Lai & Robbins, Rahul Jain et al.,
Buyukkoc, Anantharam & Varaiya, Whittle, Borkar, ...

INNOVATION PROCESS:

Caricature \longrightarrow Scheme \longrightarrow Design

Theory

Theory



Virtual Deficit

DMWM

Libin Jiang, D. Towlsey,...

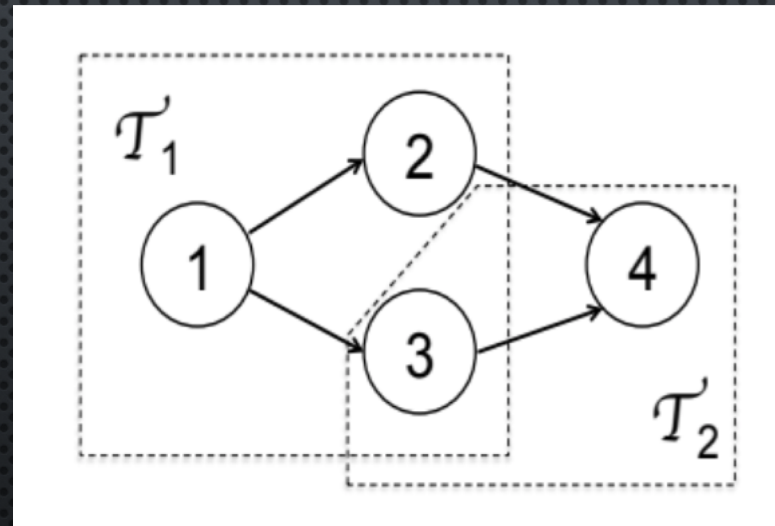
INNOVATION PROCESS:



Ramp Metering

Control

INNOVATION PROCESS:



Gradient of backlog energy
Ramtin Pedarsani, Yuan Zhong,

Adaptive server
allocation

INNOVATION PROCESS:



How congestion builds up

Effective bandwidth, quick simulation, quick estimation, pricing, ...

J. Hui, S. Parekh, Courcoubetis, R. Weber, A. Ridder, C.S. Chang, Kesidis, Olivier, G. de Veciana, I. Hsu, Konstantopoulos, Mitra et al.

INNOVATION PROCESS:



Large deviations in complex processes

Anantharam, Borkar

INNOVATION PROCESS:

Caricature  Scheme  Design

Theory

Comparing stable policies

Nick Bambos

Stability of LQF

Antonis Dimakis

Instability of maximal matching

V. Anantharam,
McKeown et al.

INNOVATION PROCESS:



Theory

Time-of-Day Pricing

J. Tsitsiklis

Neutrality

Musacchio, Schwartz, Shetty

Cyber-Insurance

Schwartz, Shetty

INNOVATION PROCESS:

Caricature  Scheme  Design

Theory

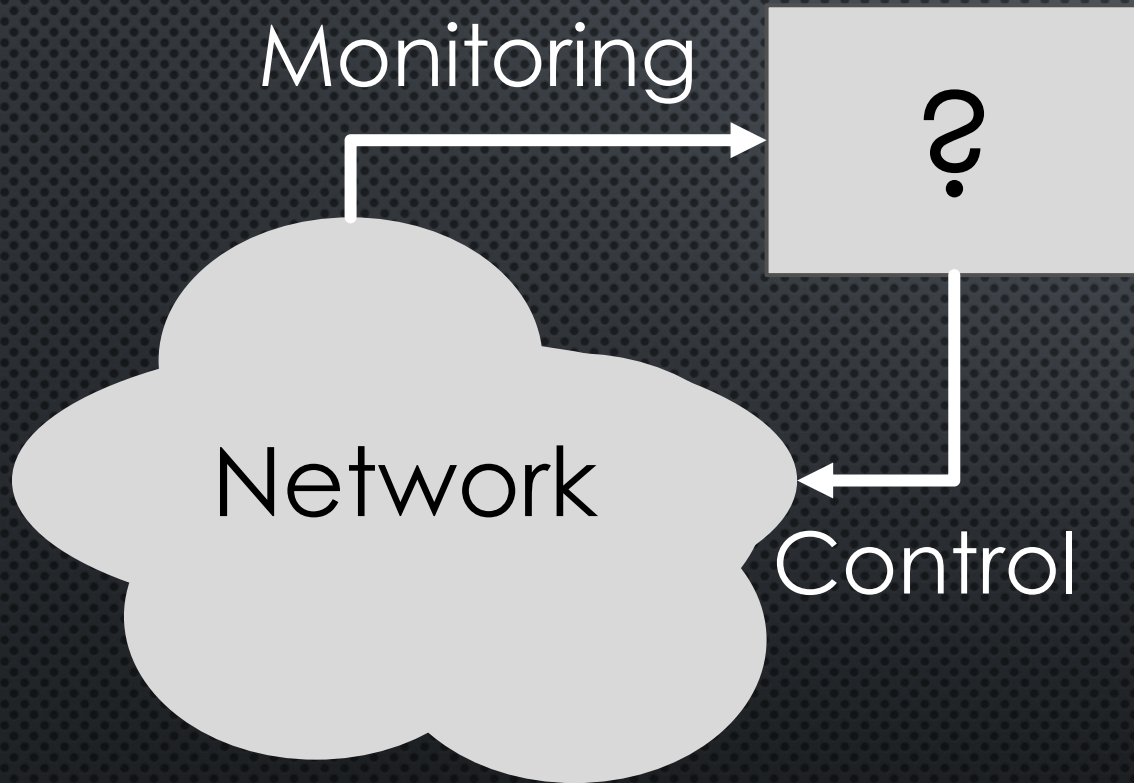
Game theory of security

Basar et al., Baras et al.,
Musacchio

Network Vulnerability

Anantharam, Gueye

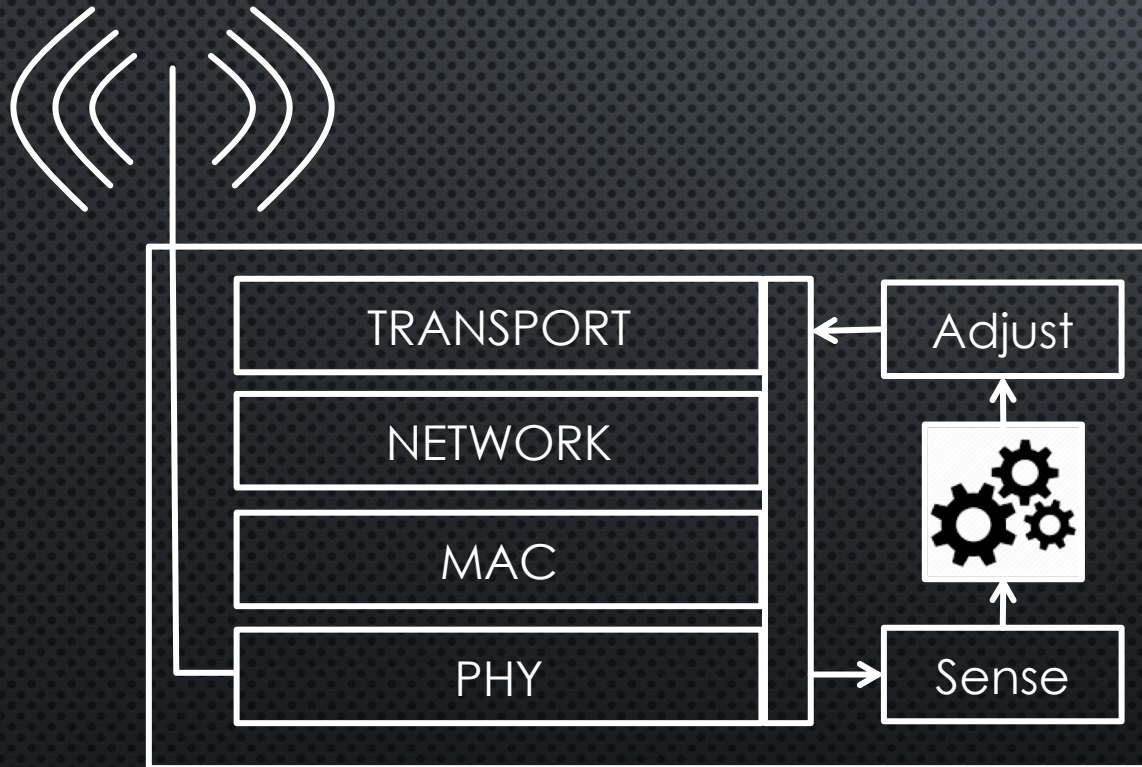
CHALLENGES: COMPLEX NETWORKS



- What information?
- What to control?
- Learning?
-

CHALLENGES: COMPLEX NETWORKS

Vision: Smart spectrum sharing, minimal standards



- WHAT TO SENSE: POWER SPECTRUM? BEACONS? PATTERNS? MACs? COLLABORATION SIGNALS?
- WHAT TO ADJUST: PHY?, MAC?, NET?, TRANS?

CHALLENGES: PROCESSING NETWORKS

- Data Centers
- Manufacturing (Tesla 3)
- Hospitals
- Service Industry

CONCLUSIONS

THEORY PROVIDES INSIGHT FOR NEW SCHEMES

- Queue per class, per flow, per destination?
- Scheduling in each node or flow control?
- Look at own queue, at neighbor's queues, at all queues, at number of flows, at committed rate, at classes of flows?
- Trunk reservation or optimization?
- Time-of-day, token-based, or dynamic pricing?
- Collaboration signals? Incentive compatibility?
-

CONCLUSIONS

THEORY PROVIDES DESIGN TOOLS FOR IMPLEMENTATION

- Multi-class TCP
- Dynamic routing
- Server allocation and flow control in processing networks
- Backpressure
- Q-CSMA
-

CONCLUSIONS

- Networking is not done!
- Much improved understanding in last few years
- Complex challenges of scale, performance, new types of networks
- The clean theoretical insights should not be obscured by the details of the technology
- Keep up the good work! We need your insight and innovations!

FINAL REMARKS

It has been quite a trip!

I thought I would stay nine months

Thanks to

Cornell, DOE, NSF, DARPA, ARO, ONR, EPFL, INRIA, and UCB

for their generous support

the industry friends at Odyssea, TeraBlaze, Dhaani, Orgo

the amazing colleagues and students

for the fun times and

for putting my name on their papers

my family and friends for their encouragement

FINAL REMARKS ...

the organizers and speakers of this workshop, all of you
for participating, the Simons Institute for hosting it

Annie for tolerating my wasting addiction to research

Pravin for preventing me from becoming a
depressed,
drunk,
washing machine repairman

THANK YOU ALL!

