Principles from the Past

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Internet 0

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My Early Years at MIT

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By ______ Date 7/24/61

July 24, 1961

Information Flow in Large Communication Nets

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May 31, 1961

Information Flow in Large Communication Nets

"The purpose of this thesis is to investigate the problems associated with information flow in large communication nets. …."

"…The nets under consideration consist of nodes, connected to each other by links. The nodes receive, sort, store, and transmit messages that enter and leave via the links…."

Under what conditions does the net jam up?

Time lapse between initiation and reception

Channel capacity

Storage capacity size

Transient behavior and recovery time

Routing doctrine

A Mathematical Theory of Data Networks

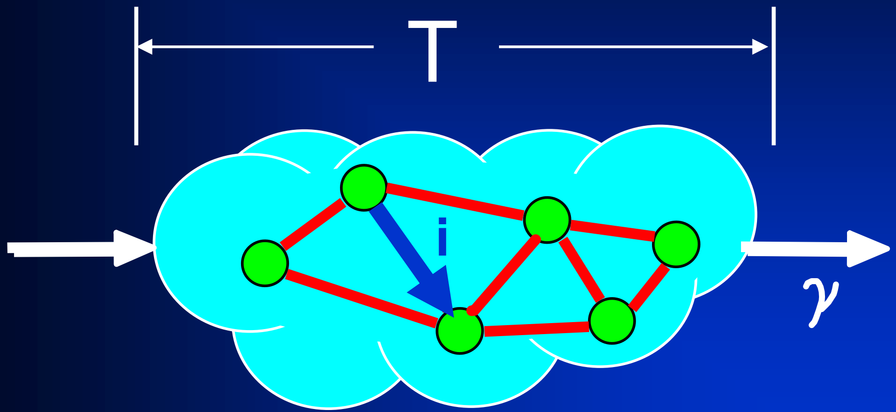
- Channel capacity limited
- Mean response time as key metric
- Analytic model set up and solved
- Optimal assignment of channel capacity
- Choice of priority queueing discipline and the introduction of packet switching
- Distributed routing procedure
- Design of topological structure
- Elucidated underlying principles of data networks

Kleinrock, L., *Communication Nets; Stochastic Message Flow and Delay,* McGraw-Hill Book Company, New York, 1964. Reprinted by Dover Publications, 1972. (Originally published as his 1962 PhD dissertation.)

Systems of Flow

1. Steady flow through a single channel
   - Trivial and deterministic
2. Unsteady flow through a single channel
   - Queueing theory; stochastics get you
3. Steady flow through a network of channels
   - Network flow theory; multicommodity gets you
4. Unsteady flow through a network of channels
   - A New domain; everything gets you!
     - Jackson's networks of queues (1957)
     - Kleinrock's Independence Assumption cracks the problem wide open

Key Equation for Networks



$$T = \sum_i \frac{\lambda_i}{\gamma} T_i$$

This is EXACT!!

T = Average network delay

λ_i = Traffic on channel i (Msg/sec)

γ = Network throughput (Msg/sec)

T_i = Average delay for channel i

But how do you find this term?

The Independence Assumption

Each time that a message is received at a node within the net, a new length is chosen for this message independently from an exponential distribution

- Without the Independence Assumption, the problem is **intractable.**
- With the Independence Assumption, the problem is **totally manageable!!**
- We get:

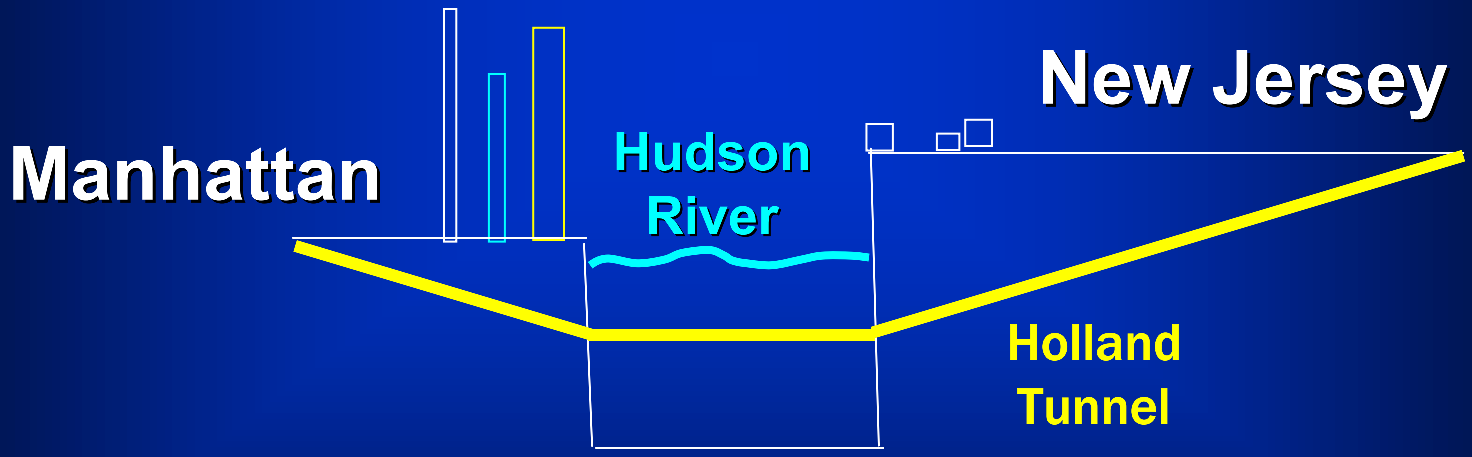
$$T_i = \frac{1}{\mu C_i - \lambda_i}$$

where $\mu C_i =$ Capacity of channel i (Msg/sec)

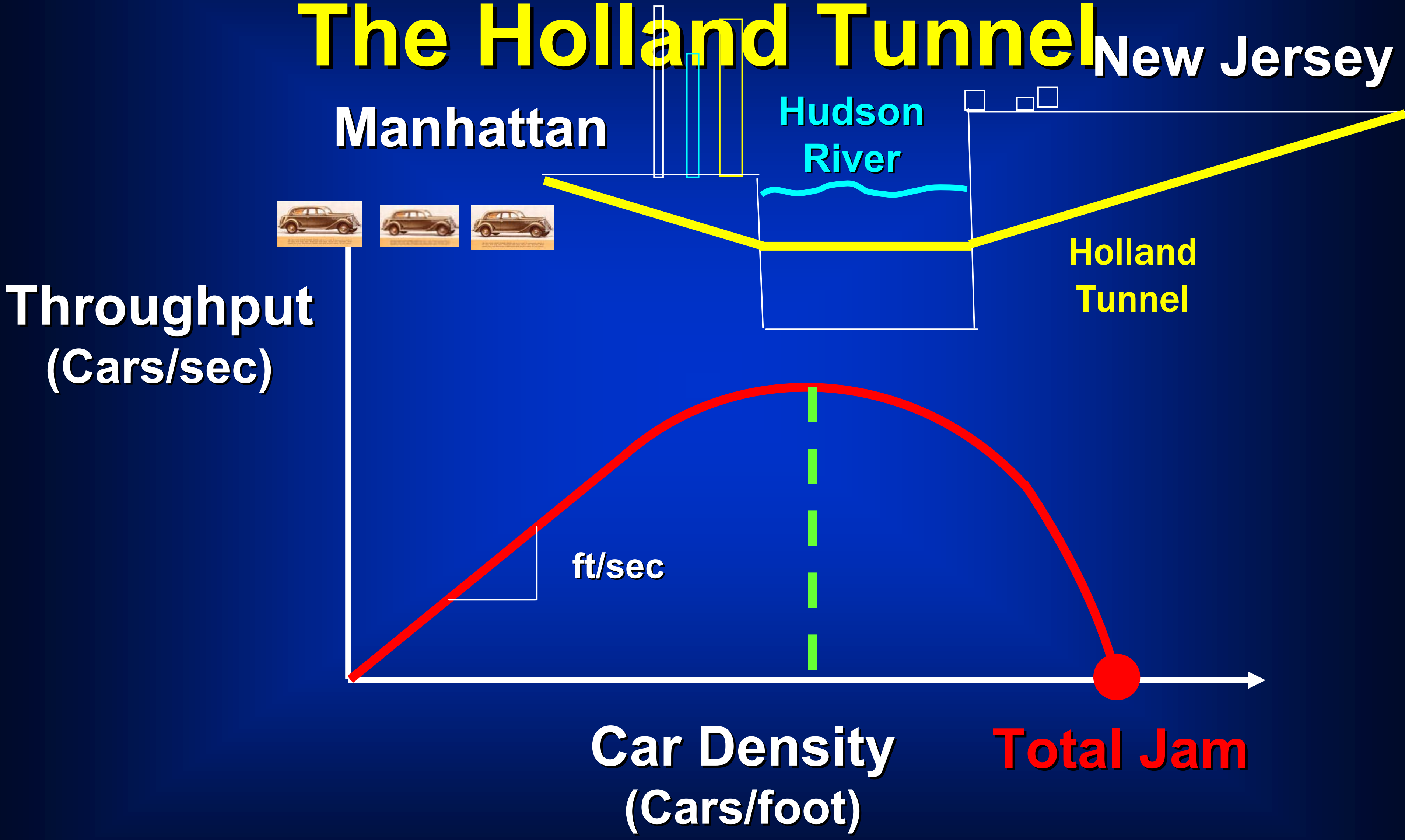
Flow Control

Seeking principles and underlying behavior

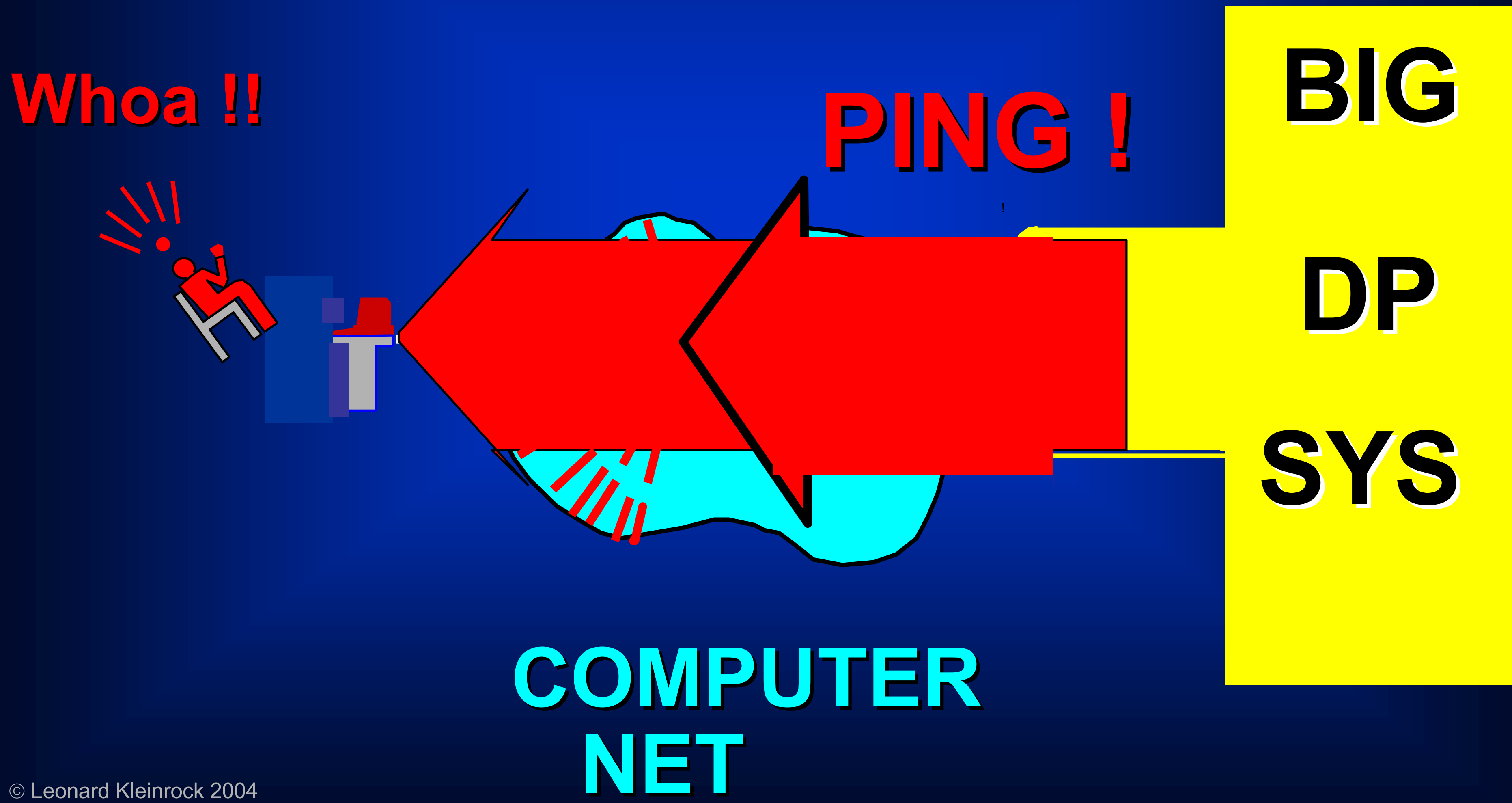
The Holland Tunnel



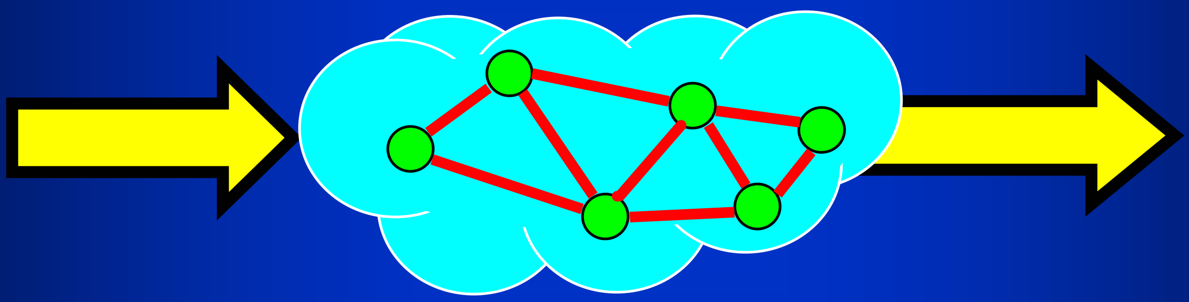
The Holland Tunnel



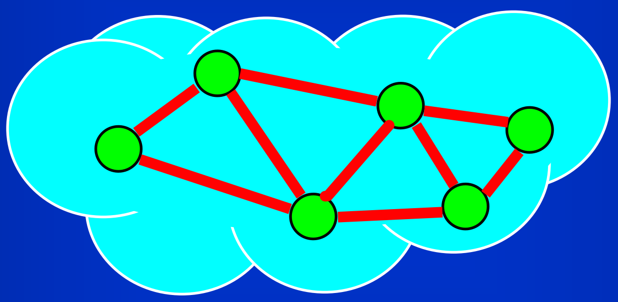
FLOW CONTROL



Constraints are Dangerous

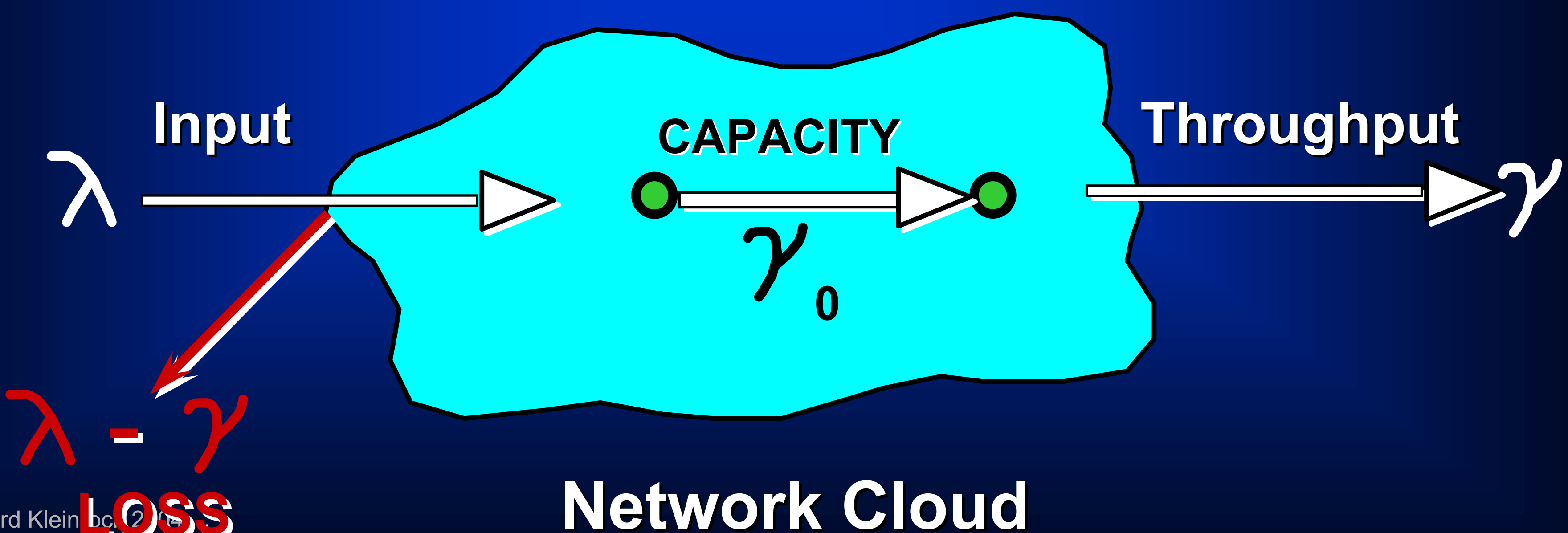


Flow Control in Networks

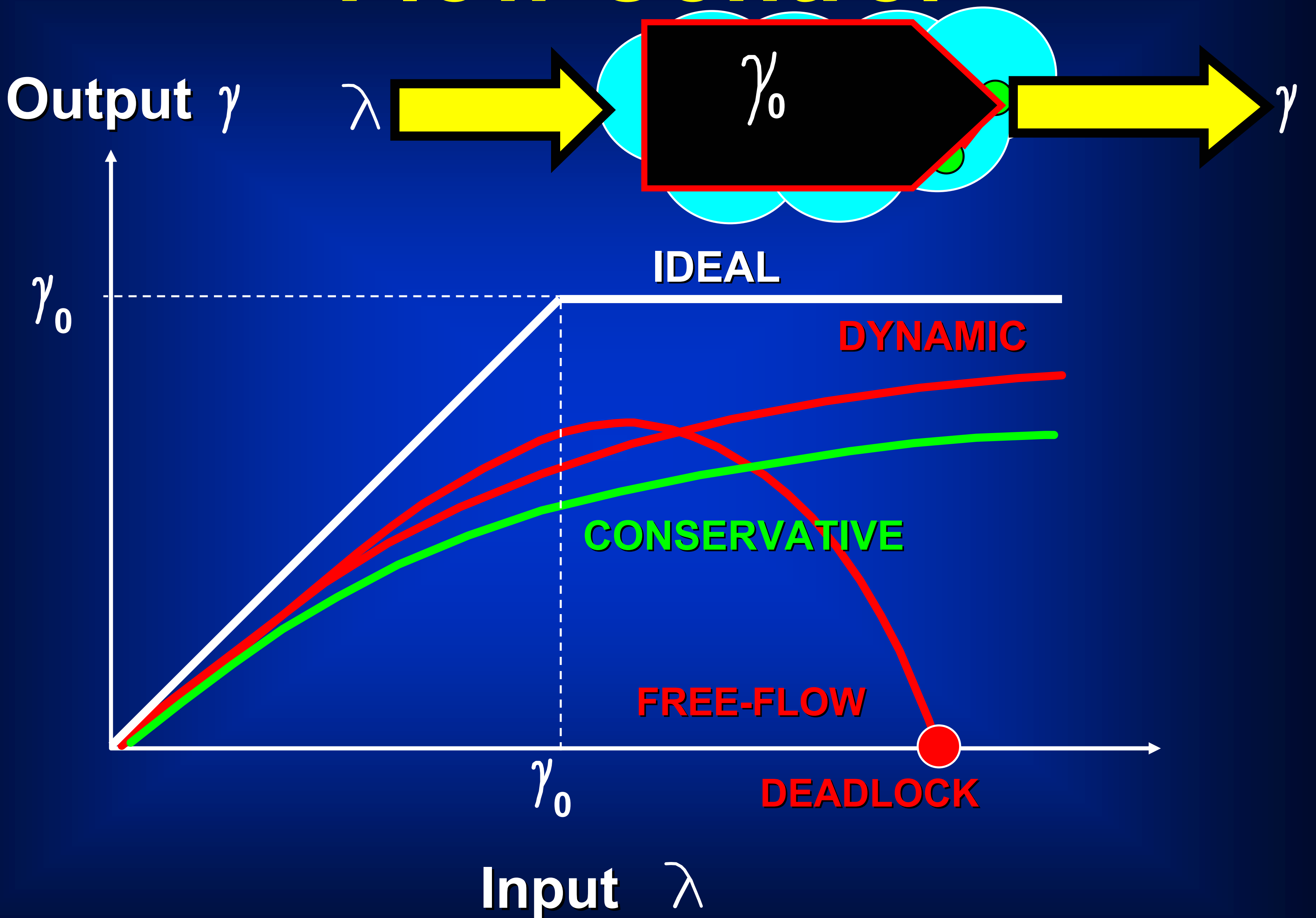


..., 3, ~~2~~, 1

Throughput
Loss



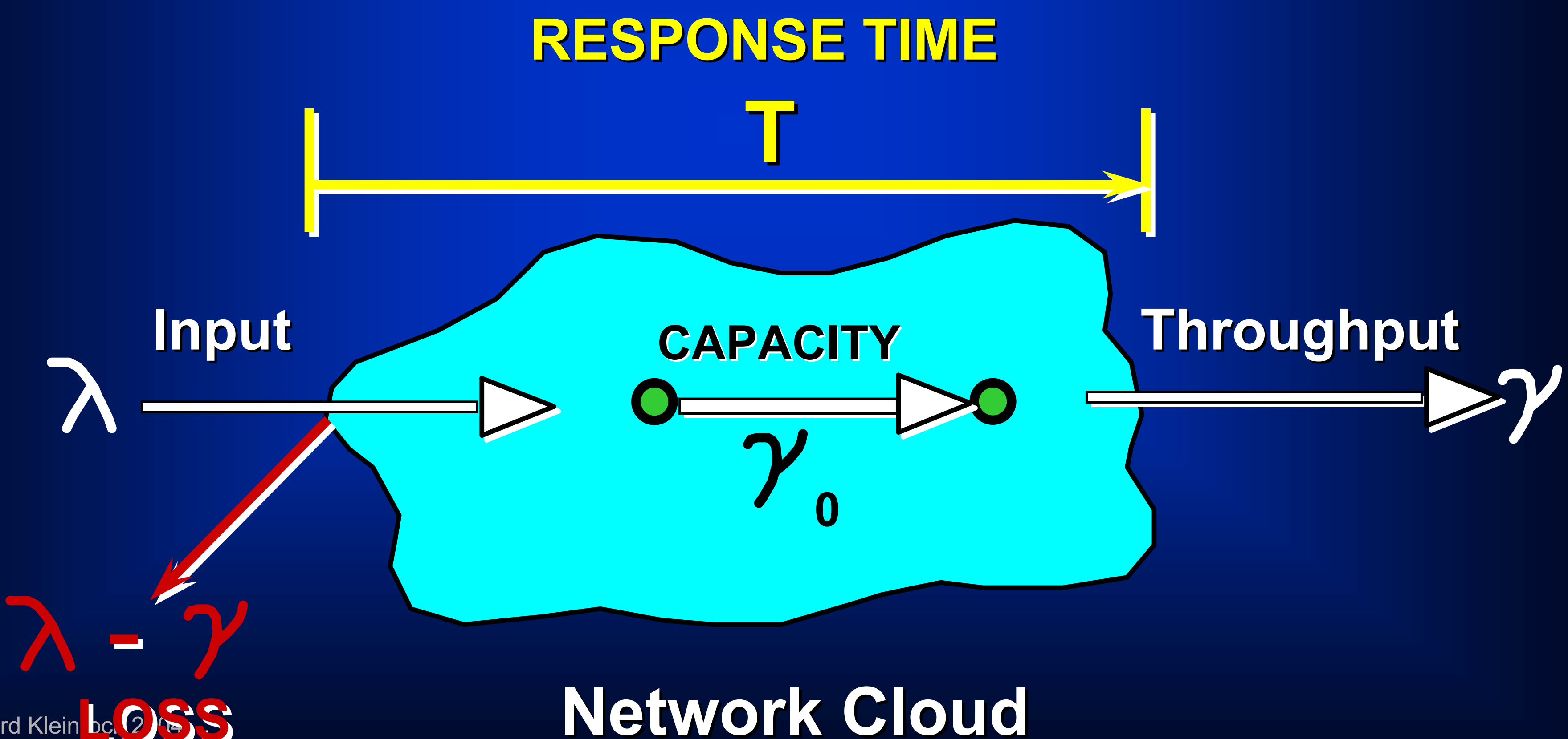
Flow Control



Distributed Control

- Routing Procedures:
  - Easy to design
  - Hard to analyze (dynamic)
- Flow Control:
  - Hard to design
  - Outrageously difficult to analyze
  - Absolutely essential
  - Guaranteed to GET you!

Response Time
Throughput
Loss

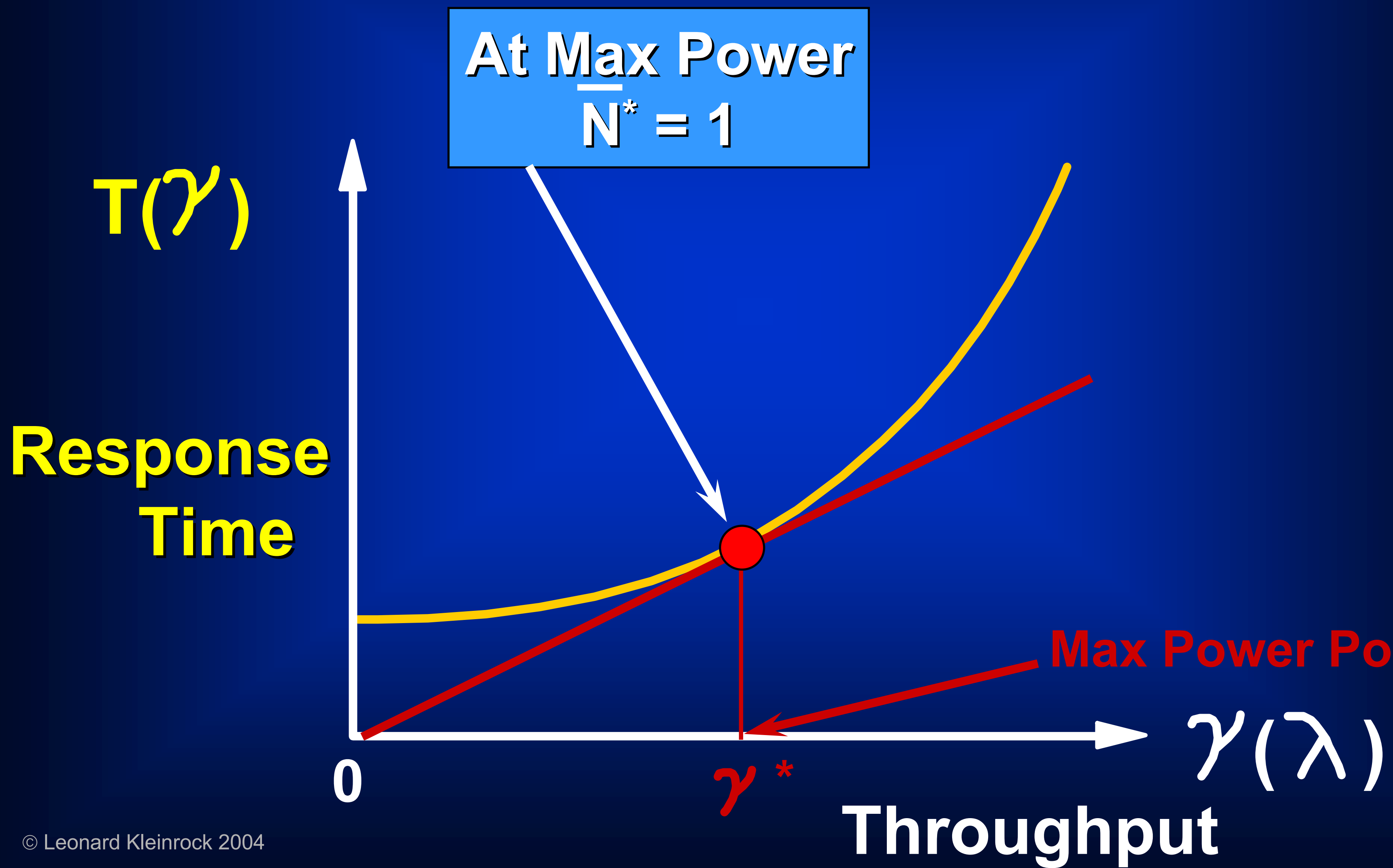


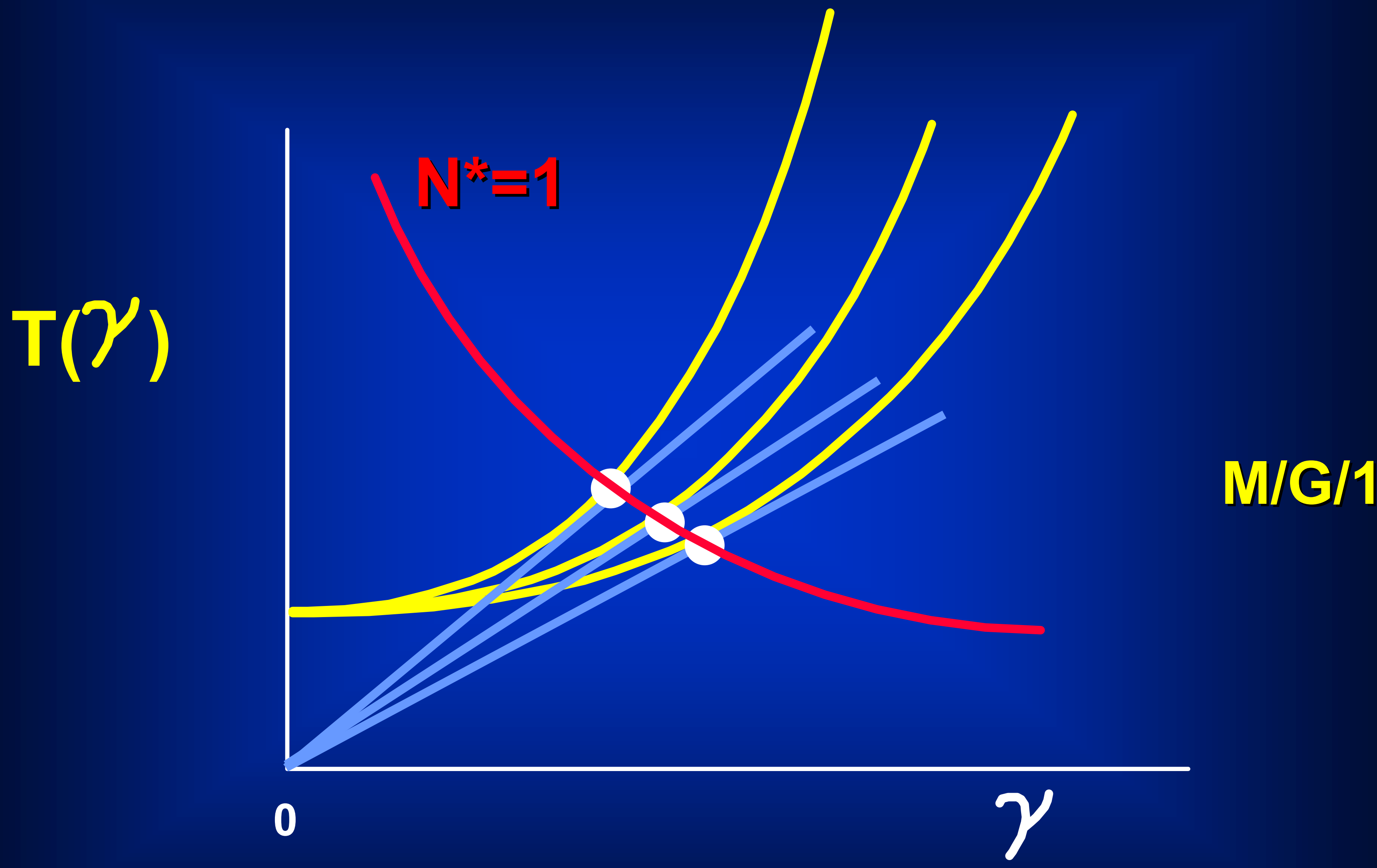
Response Time vs Throughput

$$\text{POWER} = \frac{\text{Throughput}}{\text{Response Time}} = P = \frac{\gamma}{T(\gamma)}$$

Kleinrock, L., "On Flow Control in Computer Networks", Conference Record, *Proceedings of the International Conference on Communications*, Vol. II, Toronto, Ontario, pp. 27.2.1 to 27.2.5, June 1978.

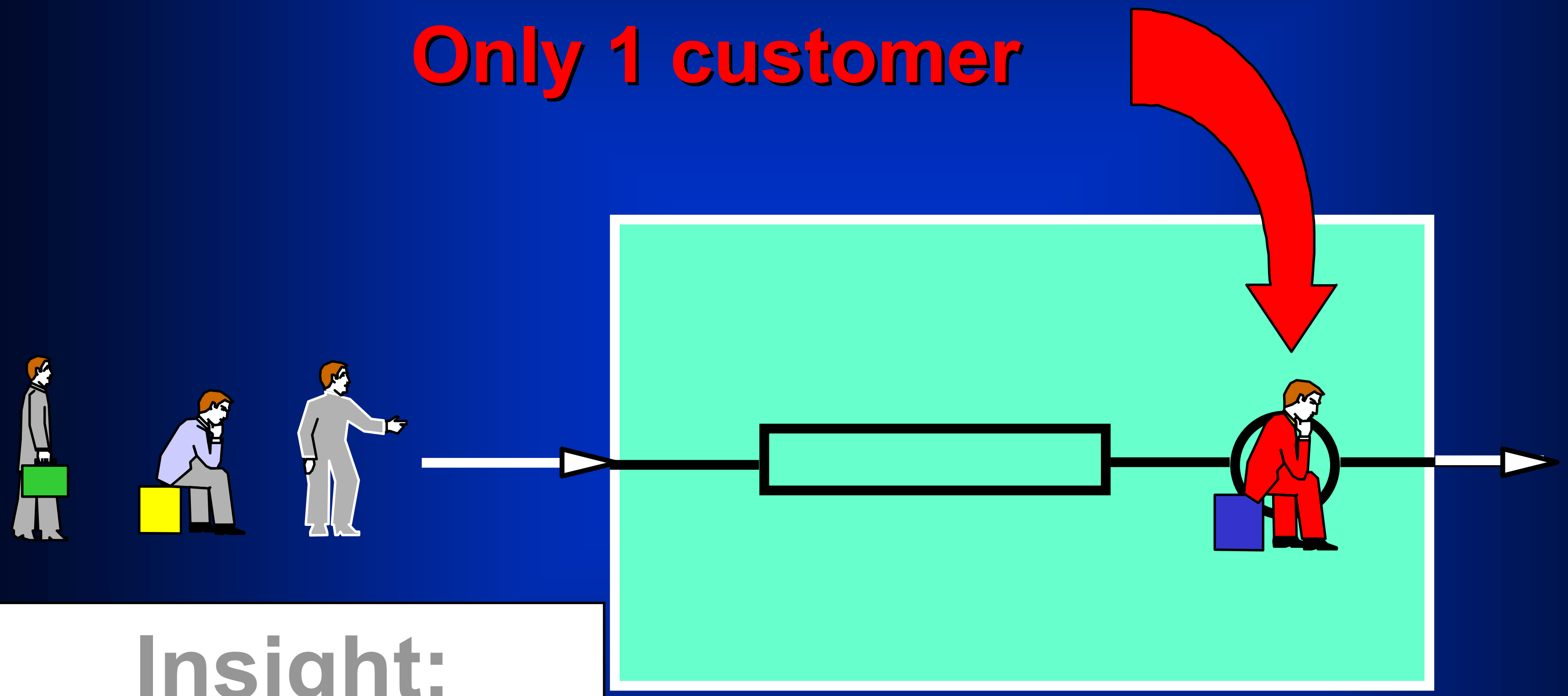
Response Time vs Throughput





T(γ)
N*=1
M/G/1
0
γ

Use Your Intuition



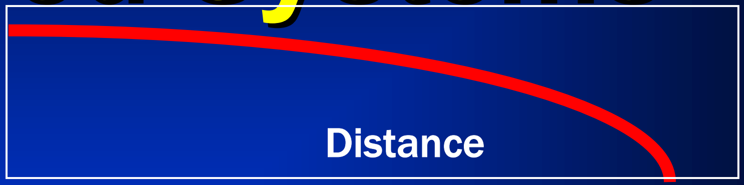
Insight:
Just keep the pipe full!

T = Min
Eff = Max

Highly Structured Systems

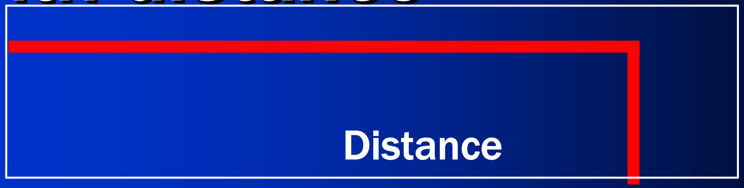
- A.M. Radio

Quality



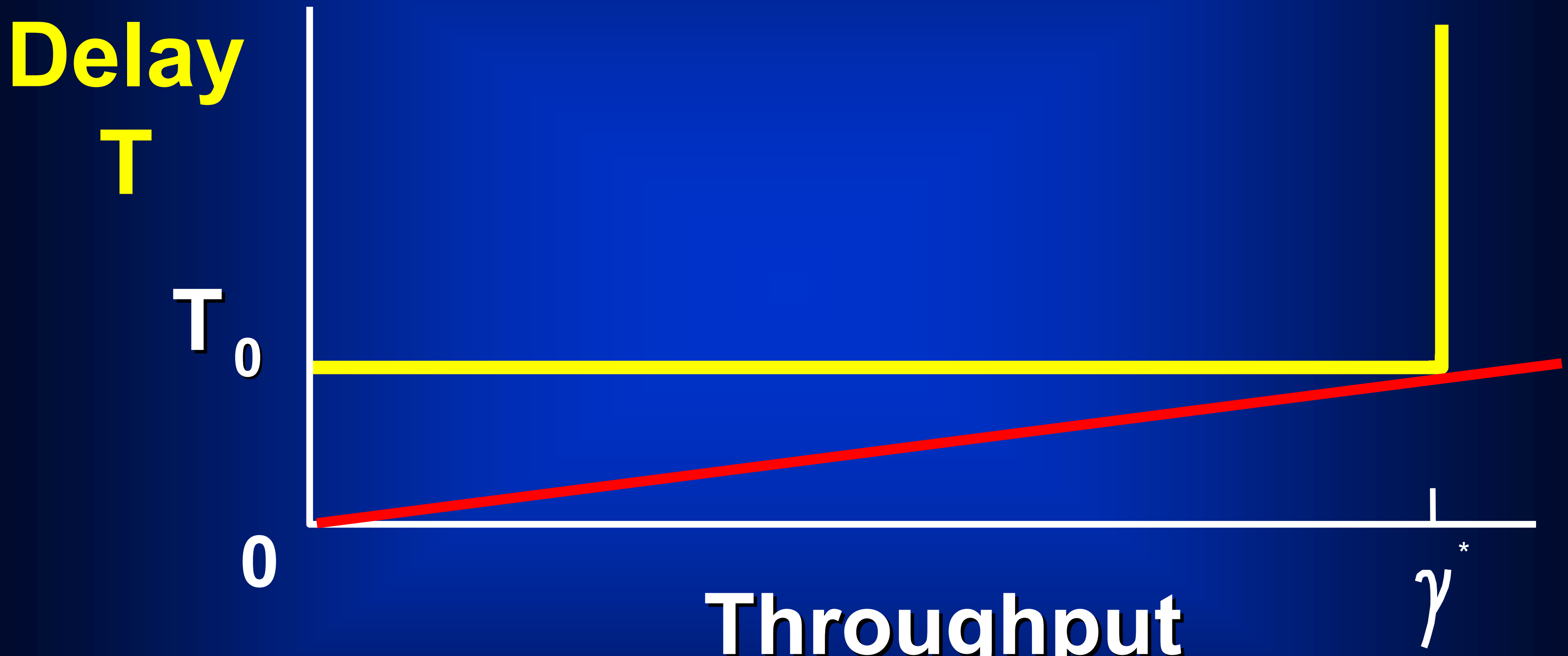
  - Poor reception
  - Slowly gets worse with distance
- F.M. Radio

Quality



  - Good reception
  - Catastrophically gets worse at critical distance
- This tends to be true for many highly structured systems
  - Congestion systems
  - Error correcting codes
  - The one horse shay

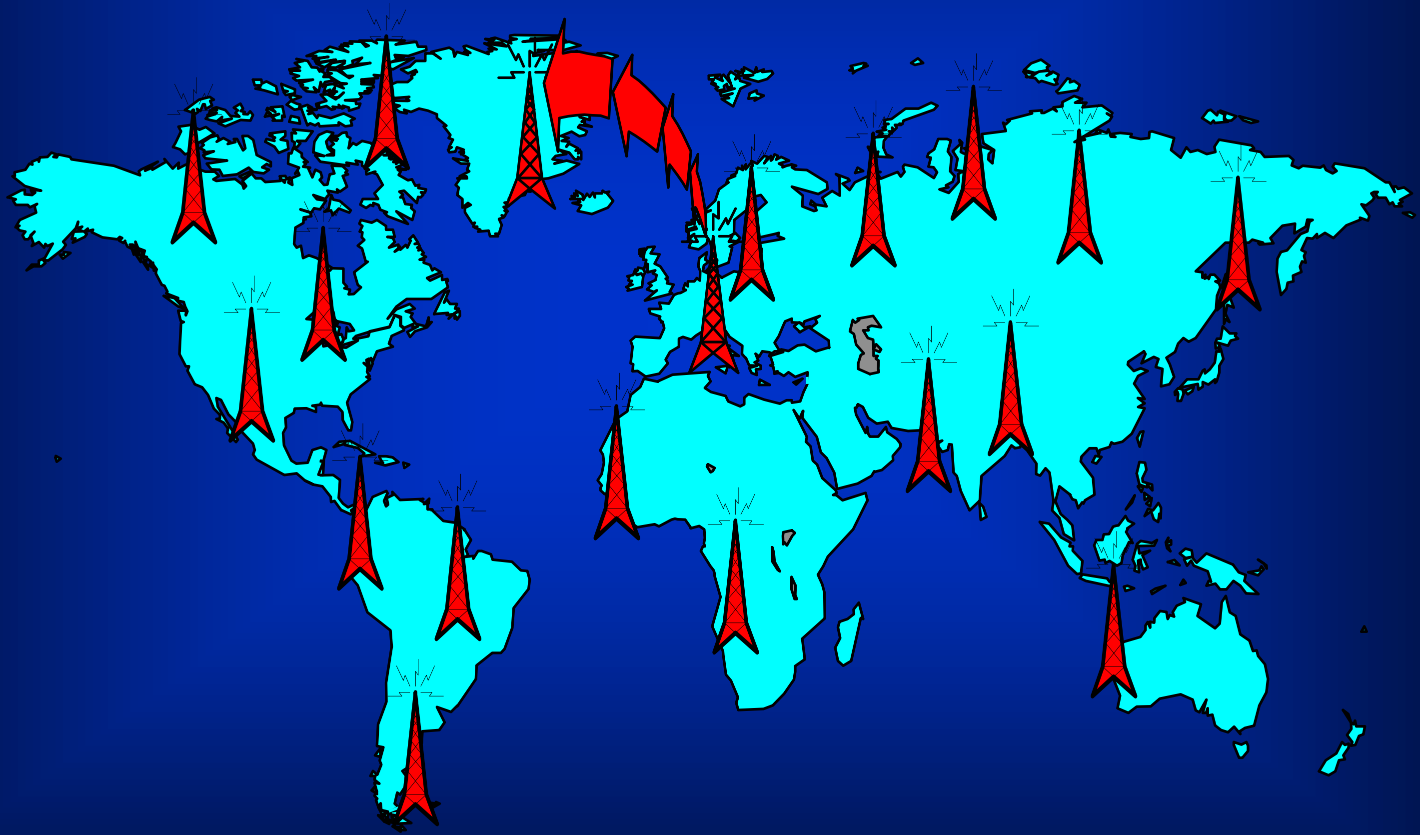
Simple 2-parameter Model For Delay



Another application of Power

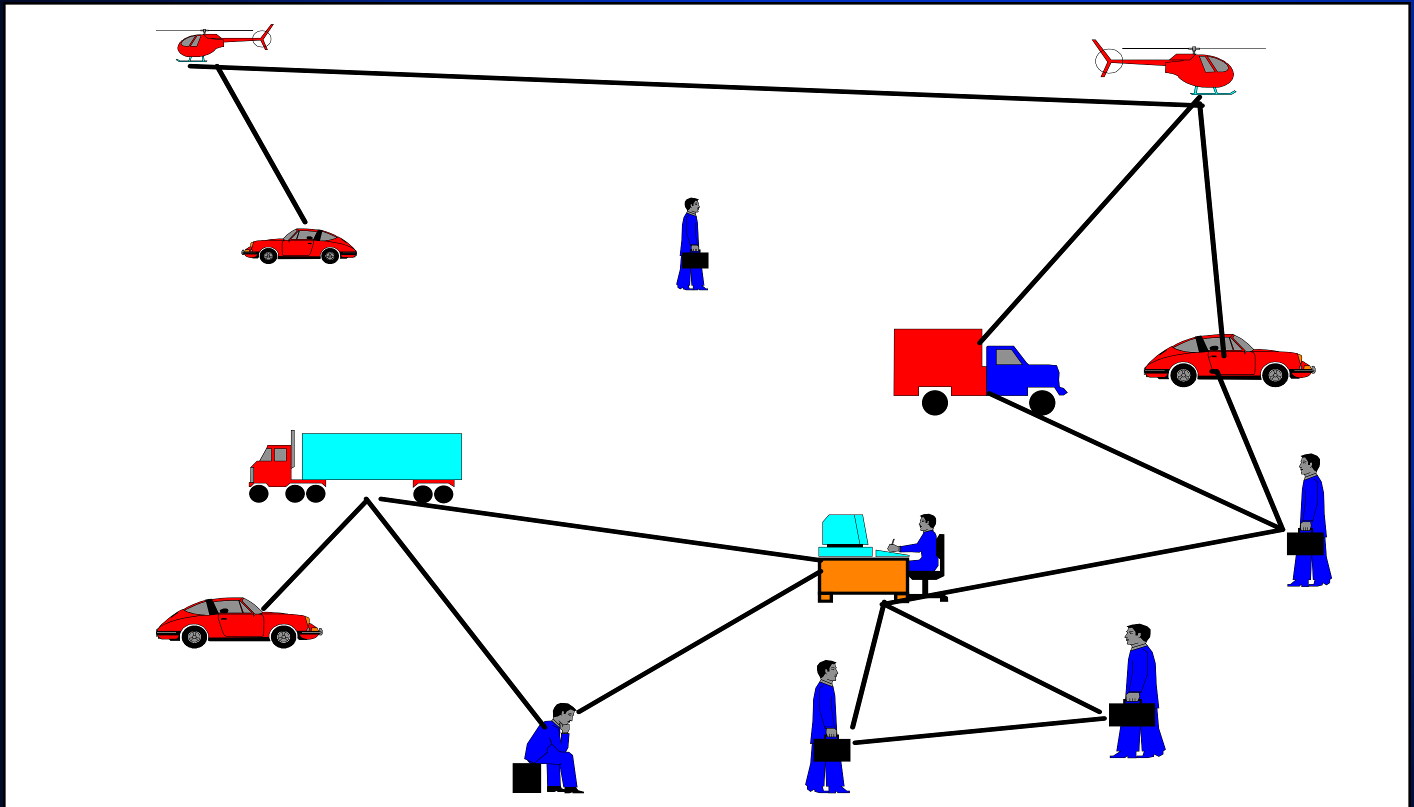
A Brief History of Radio

- Marconi 1890's



A Brief History of Pkt Radio

- 1970’s: ARPA



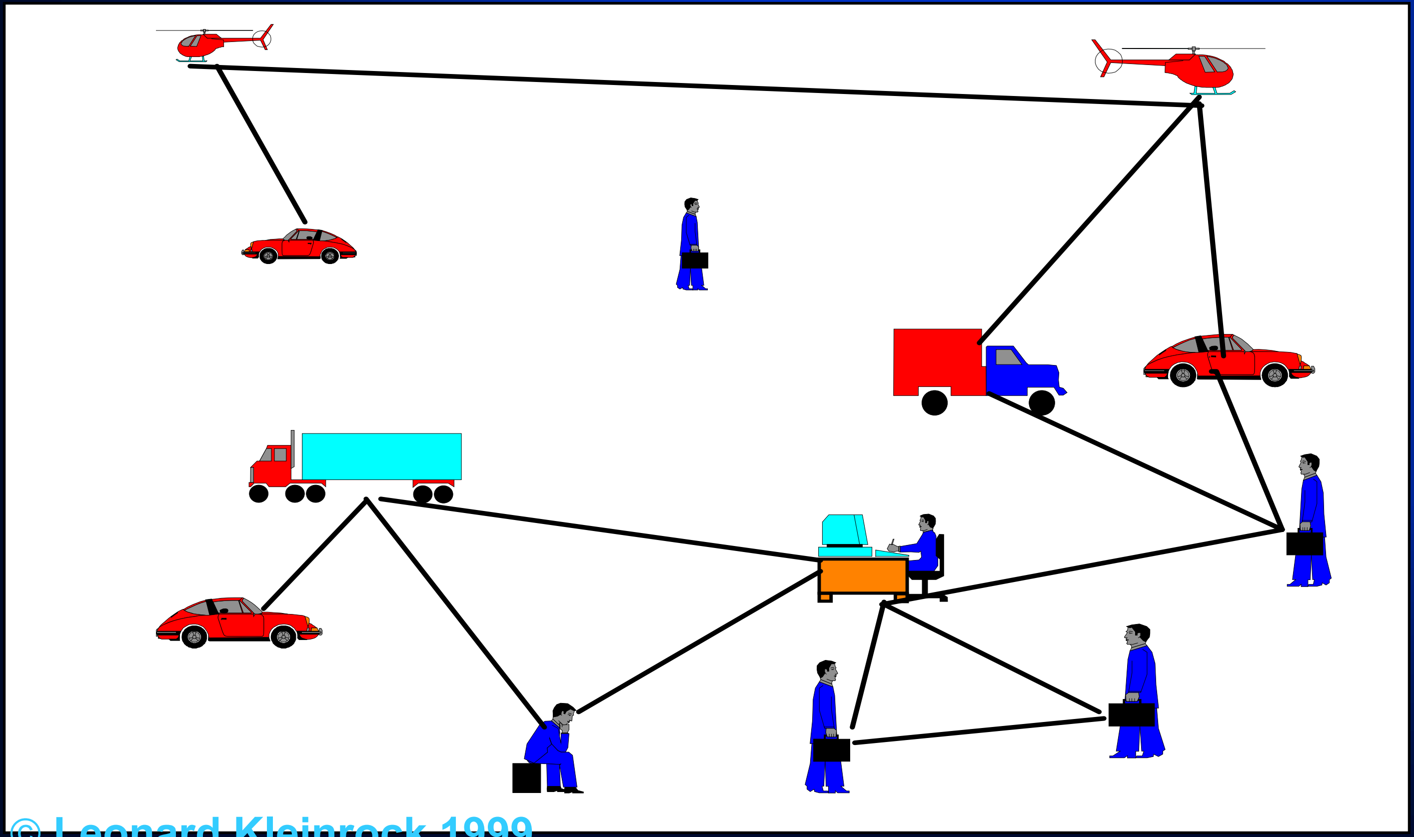
250 cu in

25 watts

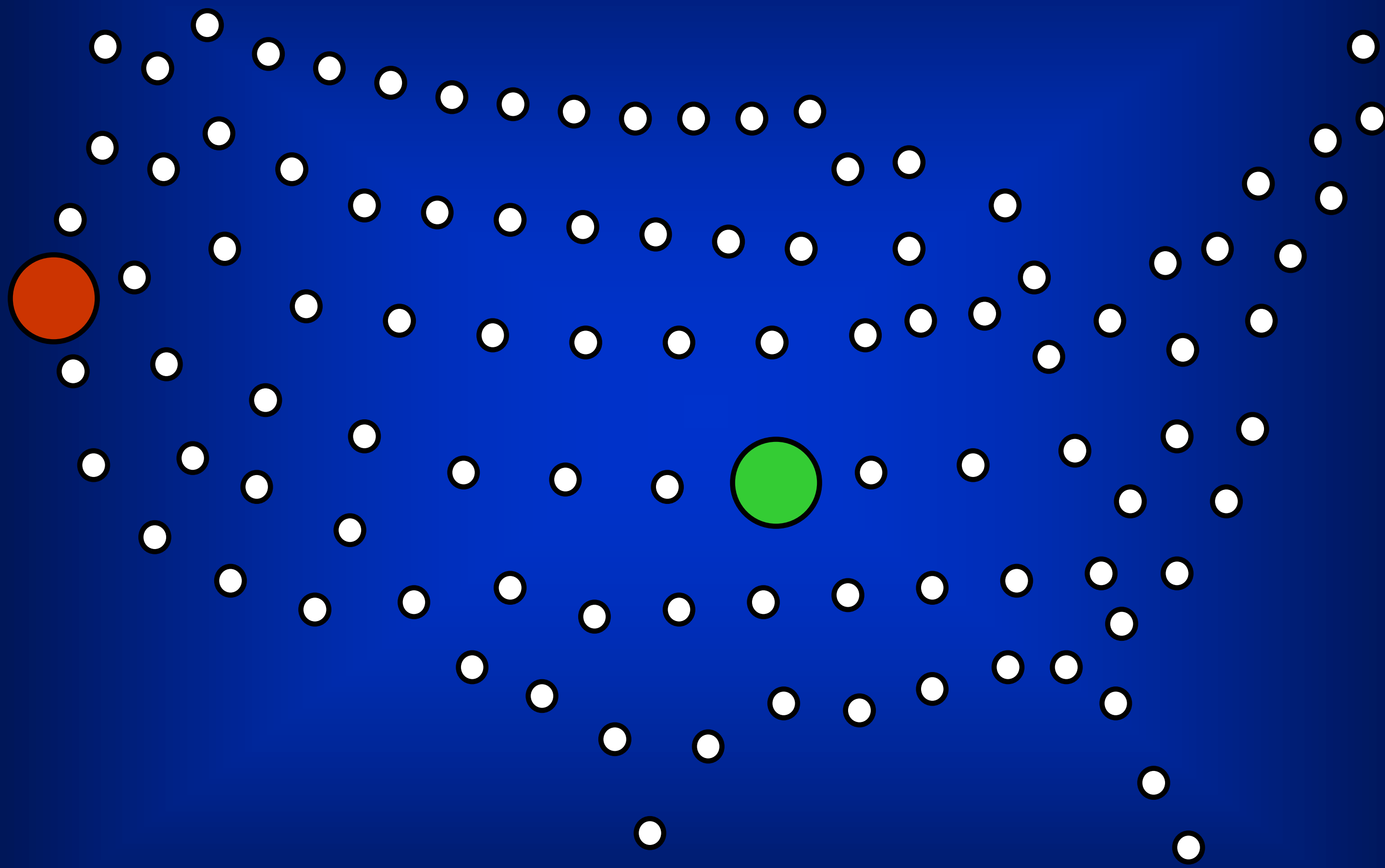
25 pounds

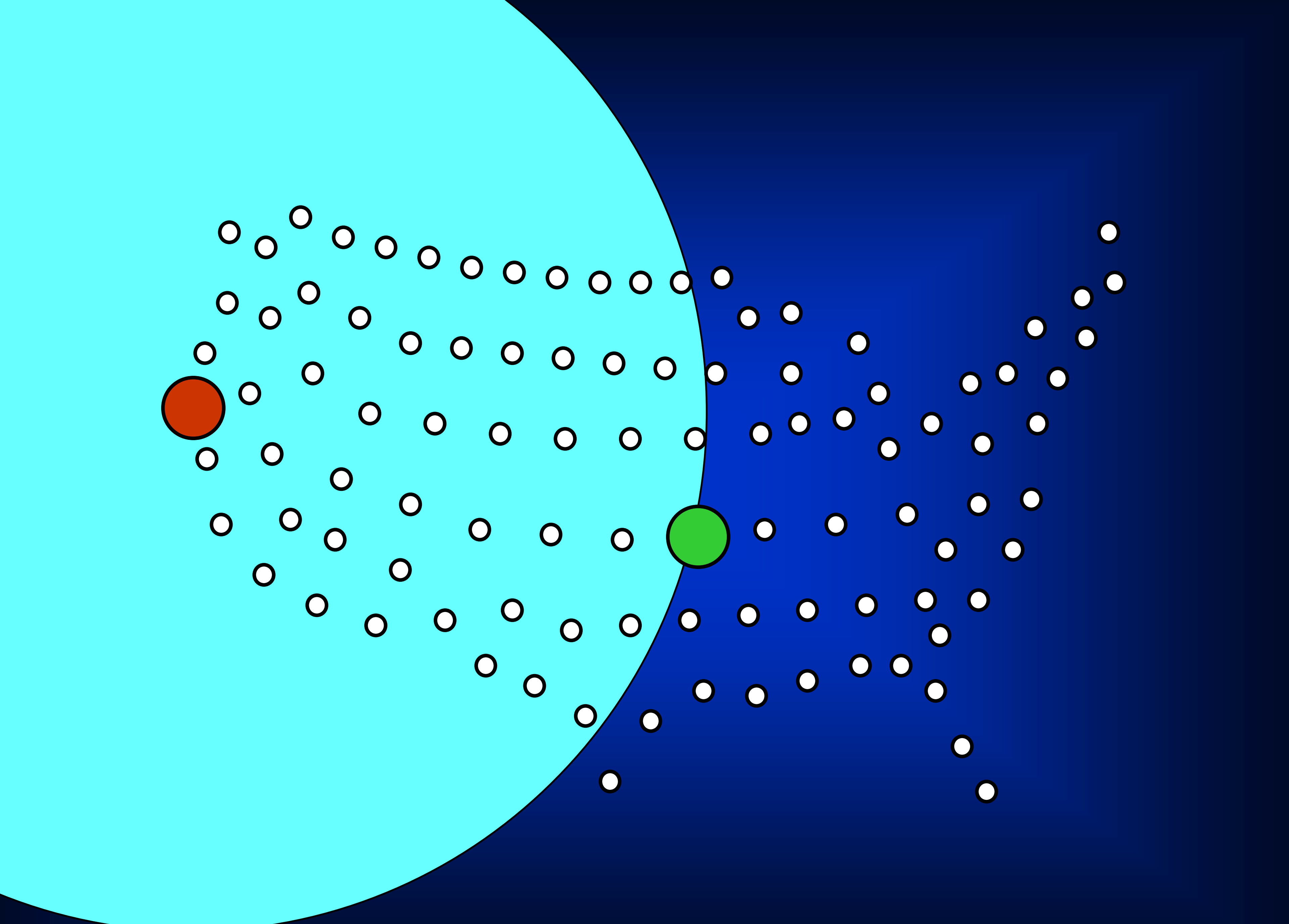
A Brief History of Pkt Radio

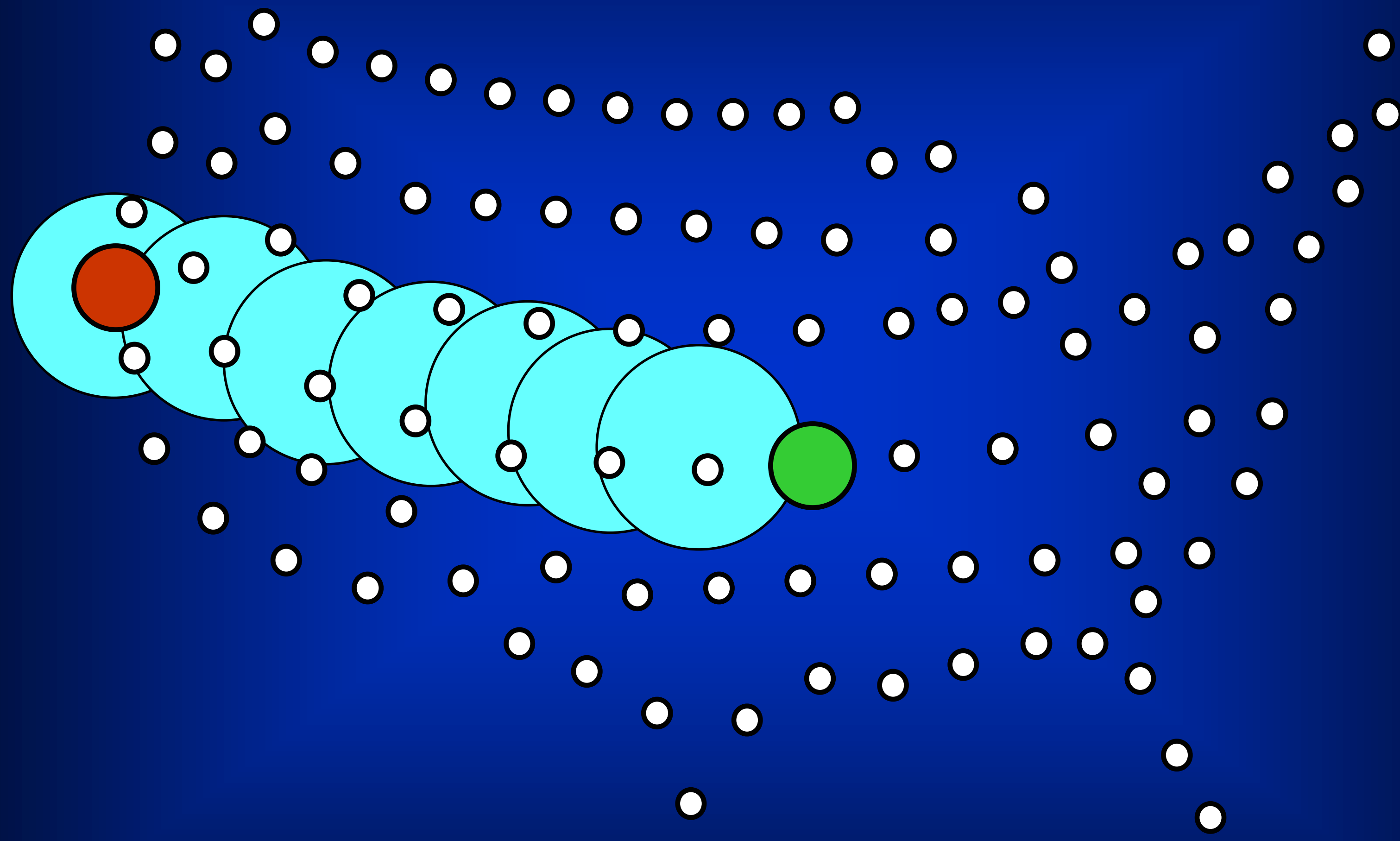
- 1990's: ARPA



10 cu in
1 watt
1 pound





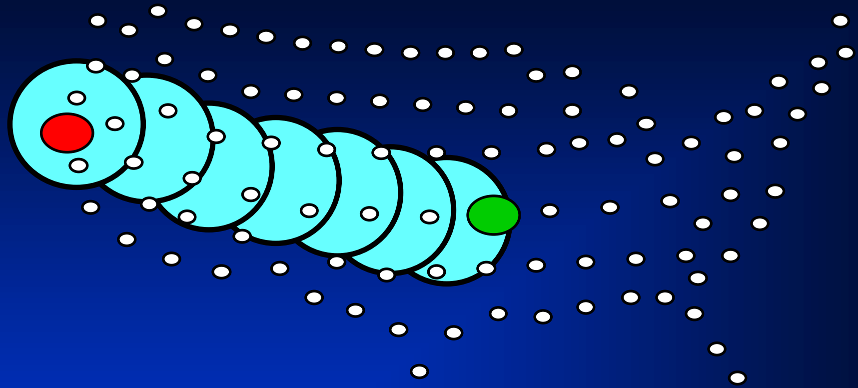


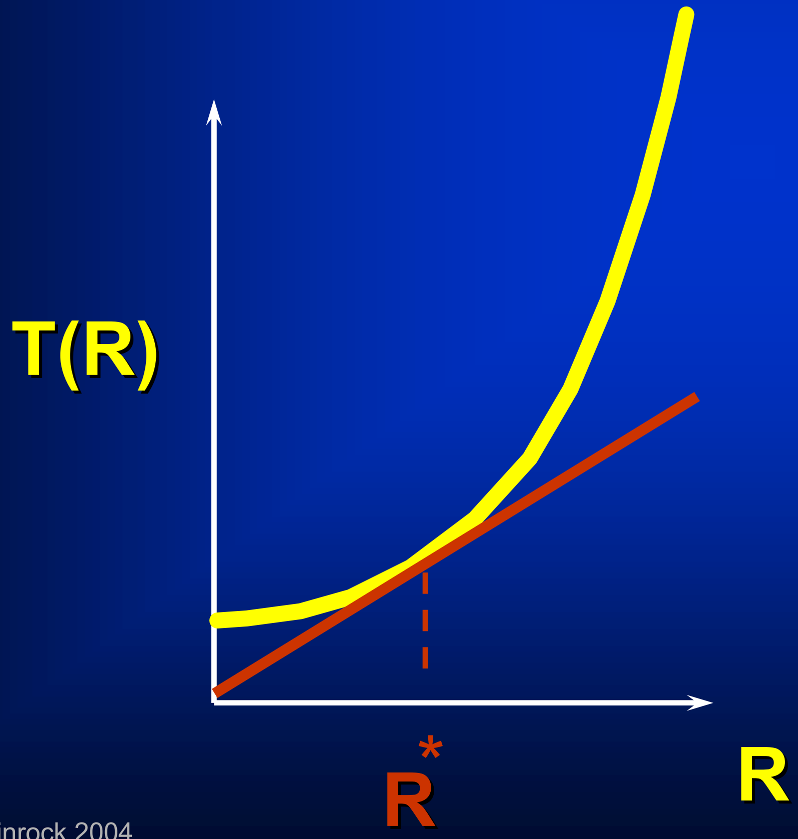
Giant Stepping
in Packet Radio

- Multihop
- Each hop covers distance R (Tx Radius)
- Total distance to cover is D (D>>R)
- Big R, more interference, fewer hops
- Small R, less interference, more hops
- Total Delay = $T(R)[D/R]$
- Choose $R=R^*$ to minimize total delay
- $dT(R)/dR = T(R)/R$ optimality condition

Kleinrock, L. "On Giant Stepping in Packet Radio Networks," *UCLA, Packet Radio Temporary Note #5, PRT 136*, March 1975.

dT(R)/dR = T/R





The General Optimization Problem (1961 LK)

- **Minimize** $$T = \sum_i \frac{\lambda_i}{\gamma} T_i$$

$$\left\{ \begin{array}{l} \text{Channel Capacity Assignment} \\ \text{Routing Procedure} \\ \text{Message queueing discipline} \\ \text{Topology} \end{array} \right\}$$

- **Subject to:** $$D = \sum_i d_i C_i$$

Where

C_i = Channel capacity of i^{th} channel

d_i = Cost to supply 1 unit of capacity to i^{th} channel

D = Total dollars available for design

Solution to the Problem

- Exact solution for $d_i = 1$
- Exact solution for arbitrary d_i
- Implications for topology
- Implications for routing procedure
- Implications for message sizes

The Underlying Principles

- Resource Sharing (demand access)
  - Only assign a resource to data that is present
  - Examples are:
    - Message switching
    - Packet switching
    - Polling
    - ATDM
- Economy of Scale in Networks
- Distributed control
  - It is efficient, stable, robust, fault-tolerant and WORKS!

Kleinrock, L., *Communication Nets; Stochastic Message Flow and Delay,* McGraw-Hill Book Company, New York, 1964. Reprinted by Dover Publications, 1972. (Originally published as his 1962 PhD dissertation.)

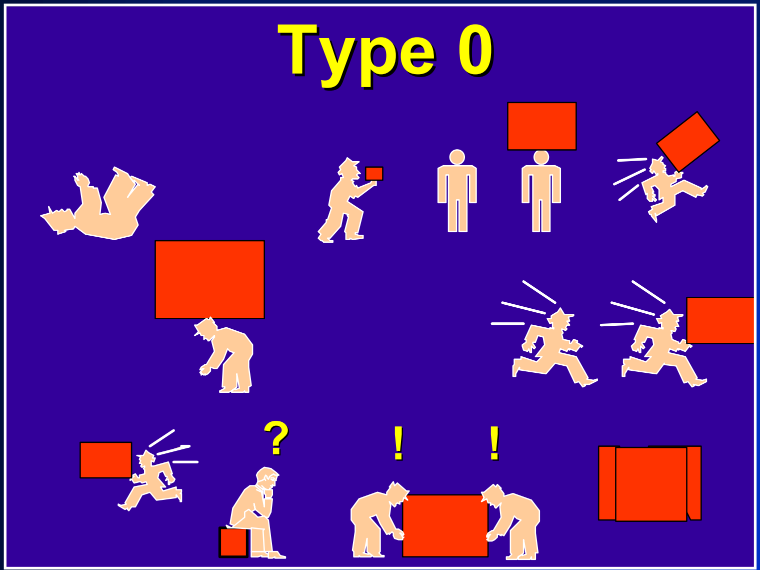
Bursty Asynchronous Demands

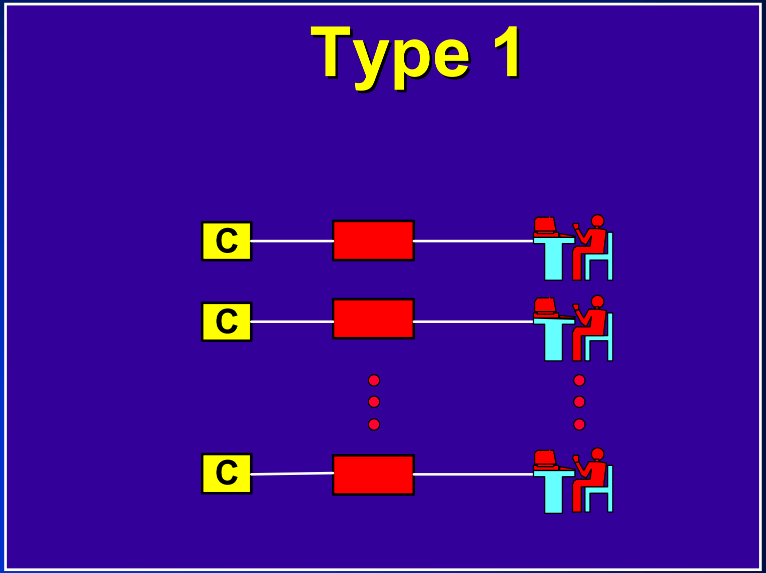
- You cannot predict exactly **when** they will demand access
- You cannot predict **how much** they will demand
- Most of the time they **do not need** access
- When they ask for it, they want **immediate** access!!

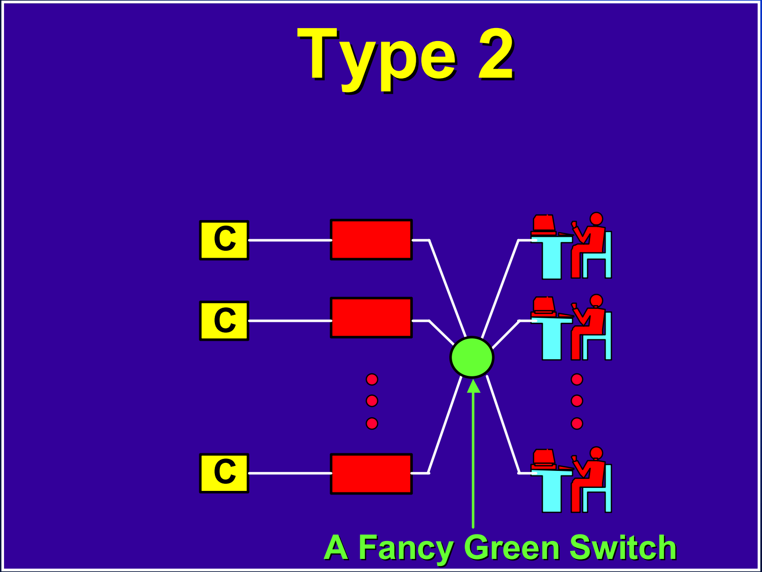
Conflict Resolution

- **Queueing:**
  - One gets served
  - All others wait
- **Splitting:**
  - Each gets a piece of the resource
- **Blocking:**
  - One gets served
  - All others are refused
- **Smashing:**
  - Nobody gets served !

Resource Sharing



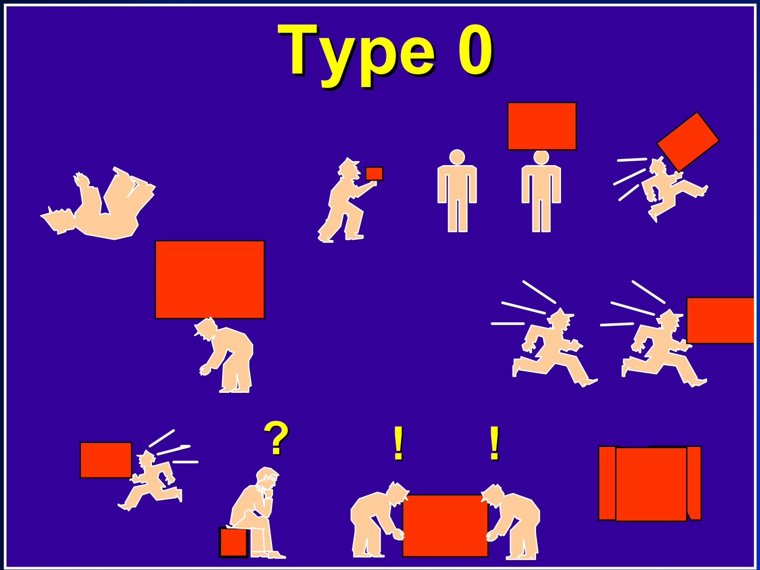


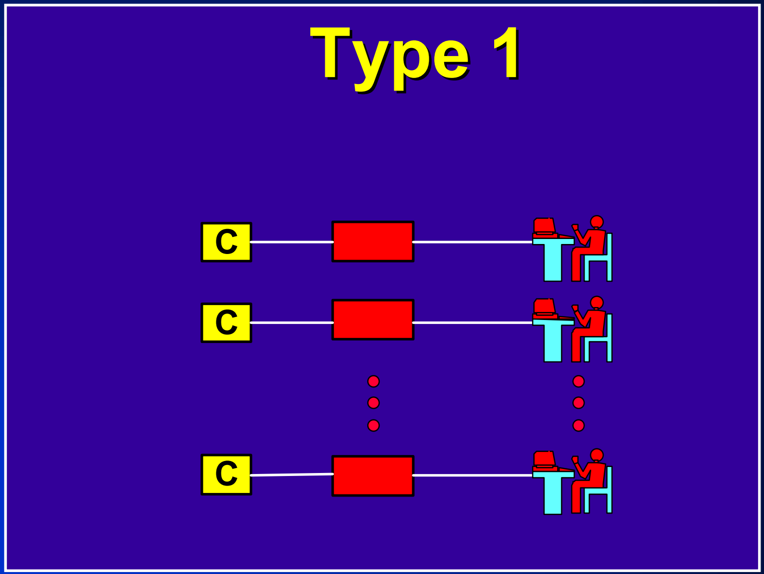


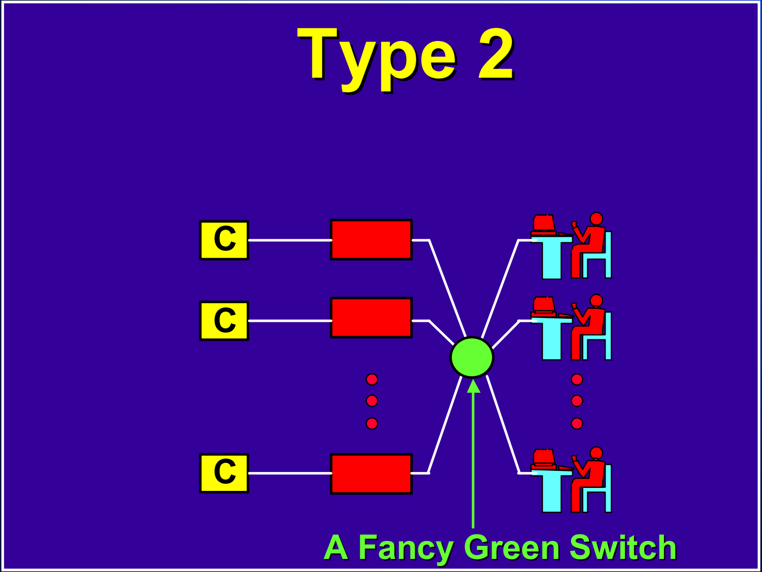
The Law of Large Numbers
(The First Resource Sharing Principle)

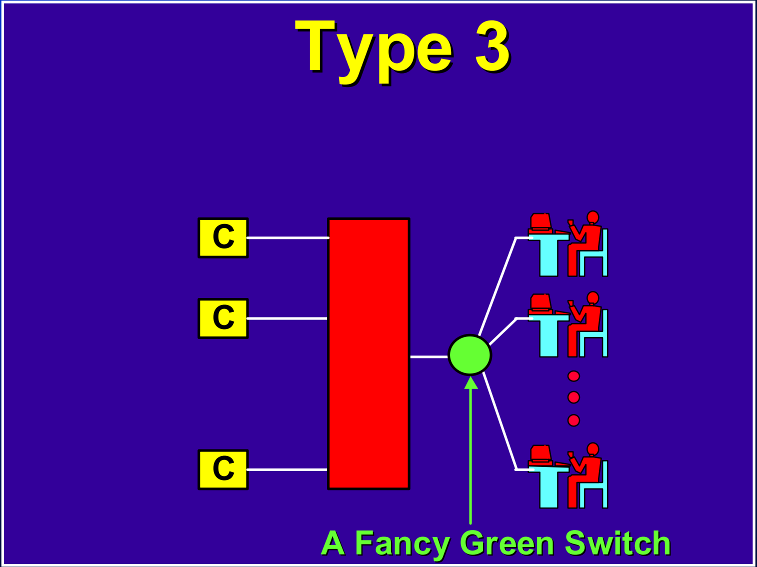
- Although each member of a large population may behave in a random fashion, the population as a whole behaves in a predictable fashion.
- This predictable fashion presents a total demand equal to the sum of the average demands of each member.
- This is the "smoothing effect" of large populations.

Resource Sharing





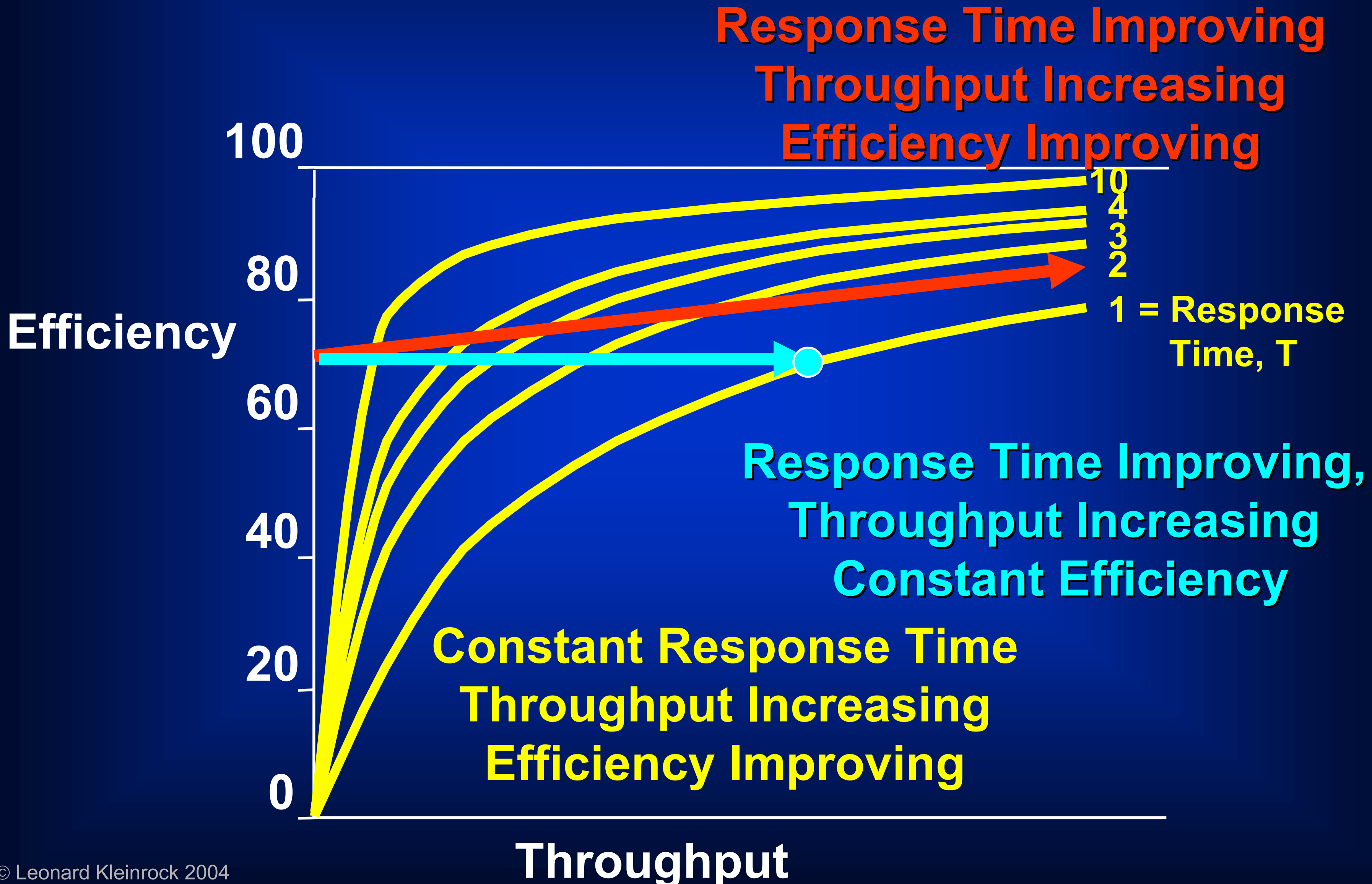




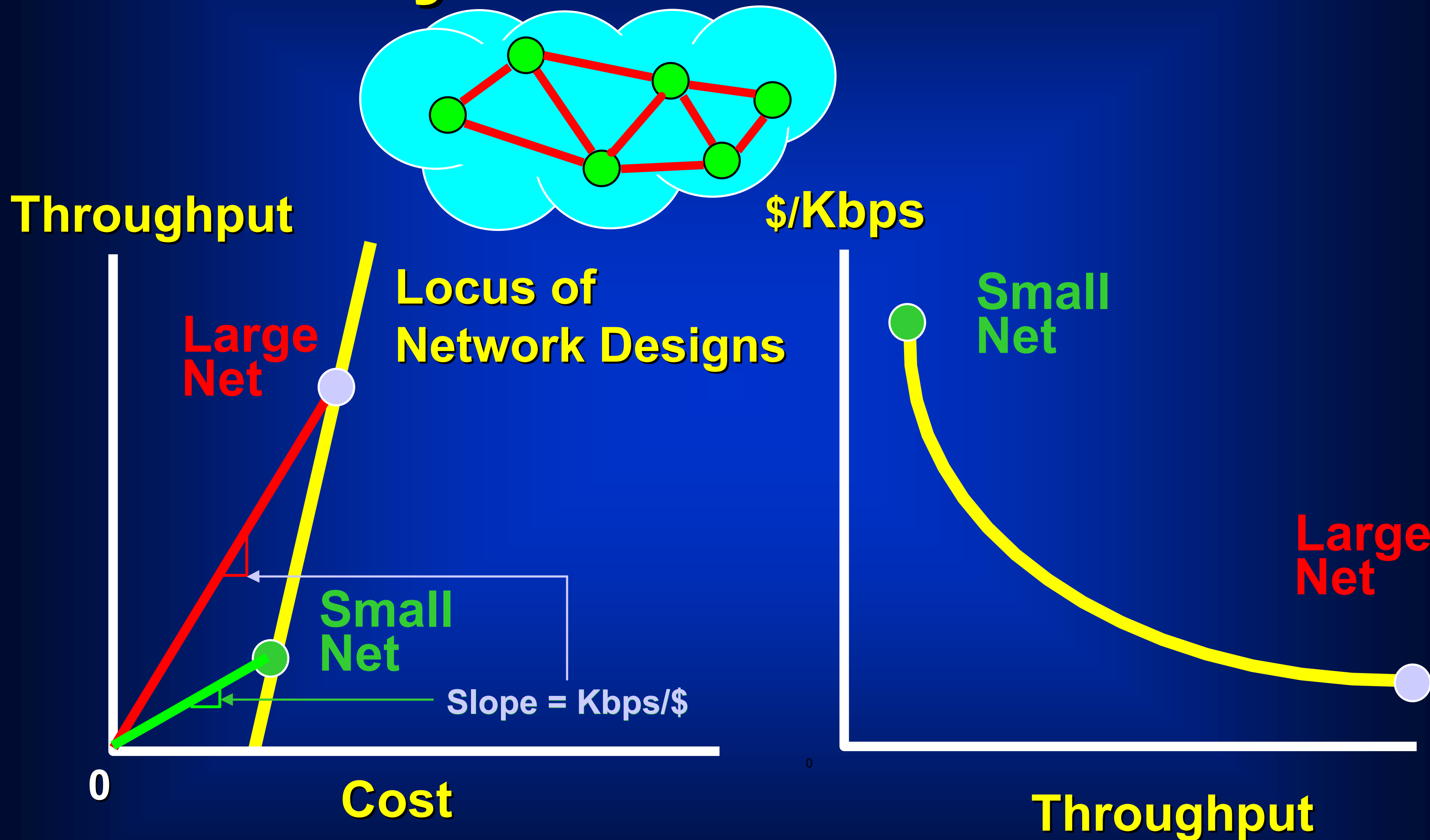
The Economy of Scale
(The Second Resource Sharing Principle)

- If you scale up throughput and capacity by some factor F, then you reduce response time by that same factor.
- If you scale capacity more slowly than throughput while holding response time constant, then efficiency will increase (and can approach 100%).

Key Tradeoff:
Response Time, Throughput, Efficiency



Economy of Scale in Networks



Key System Parameter

a = Propag Delay/Pkt Tx Time

= 5LC/b (# packets in cable)

C = Bandwidth (megabits/sec)

L = Cable Length (kilometers)

PD = 5L (microseconds)

	SPEED MBPS	PKT LNGTH BITS	PROP DELAY MICROSEC	LATENCY a
LOCAL NET	10.00	1,000	5	0.05
WIDE AREA NET	0.05	1,000	20,000	1.00
SATELLITE	0.05	1,000	250,000	12.50
FIBER LINK	1,000.00	1,000	20,000	20,000.00
INTERNET 0	1.00	1,000	0.3	0.0003

Conclusions

- Flow control is needed and tough
- Look for principles
- Be aware of prior work
- Don’t fall in love with your model

Thank You

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