Beyond the Netherworld of Cyberspace

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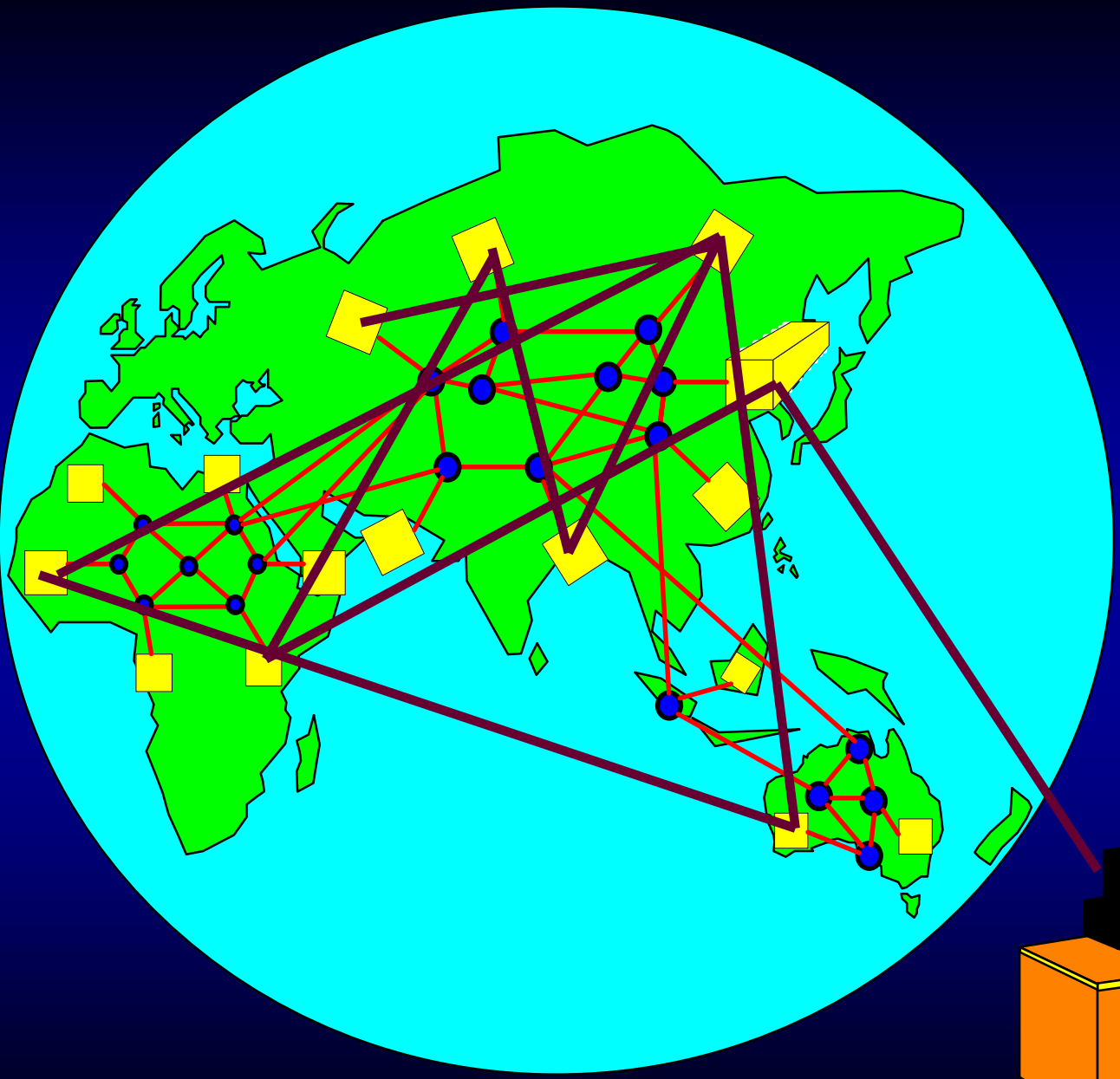
MobiHOC
Boston, MA
August 11, 20000

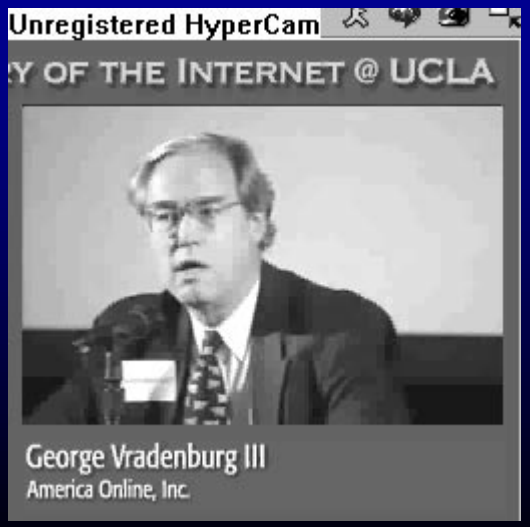
The Web as Most People See It!



“A user does not understand what is happening behind the computer screen….”

“…The future is in the art of making it disappear”

George Vrandenburg III,
SVP AOL
September, 1999



The Culture of the Web

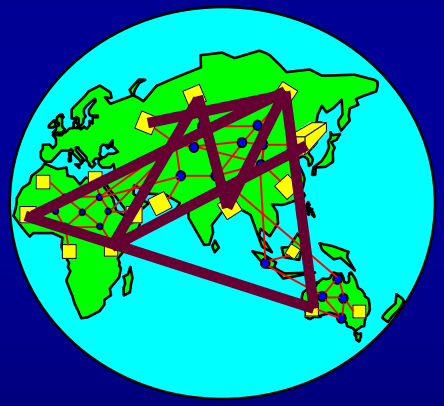
- My early design philosophy:
  - Every router shares in controlling the network
- ARPA's philosophy:
  - Give good researchers freedom and funding
- Research leaders passed this philosophy on:
  - Give graduate students freedom and funding
- Graduate students passed this philosophy on:
  - Share ideas among yourselves and all other users
- Millions of Internet users now contribute their ideas and creativity to make the Internet the major force it is today.
- Open, shared, no one controls it, no one can shut it off, communities of interest

How Big is the Web?

- 1 billion web pages
- 300 million users worldwide
  - 2/3 of Americans (over 12) used Internet in past year
  - 1/3 of Americans (over 12) go online daily
- Years to reach 50 million people:
  - Radio 38
  - TV 13
  - Cable 10
  - Internet (commercial) 5

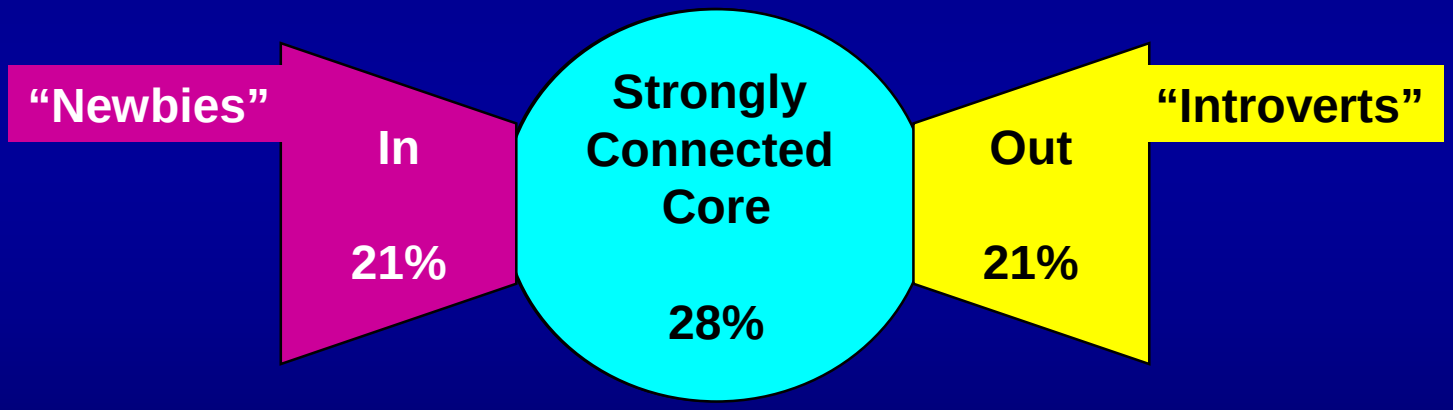
The Structure of the Web

Strongly Connected

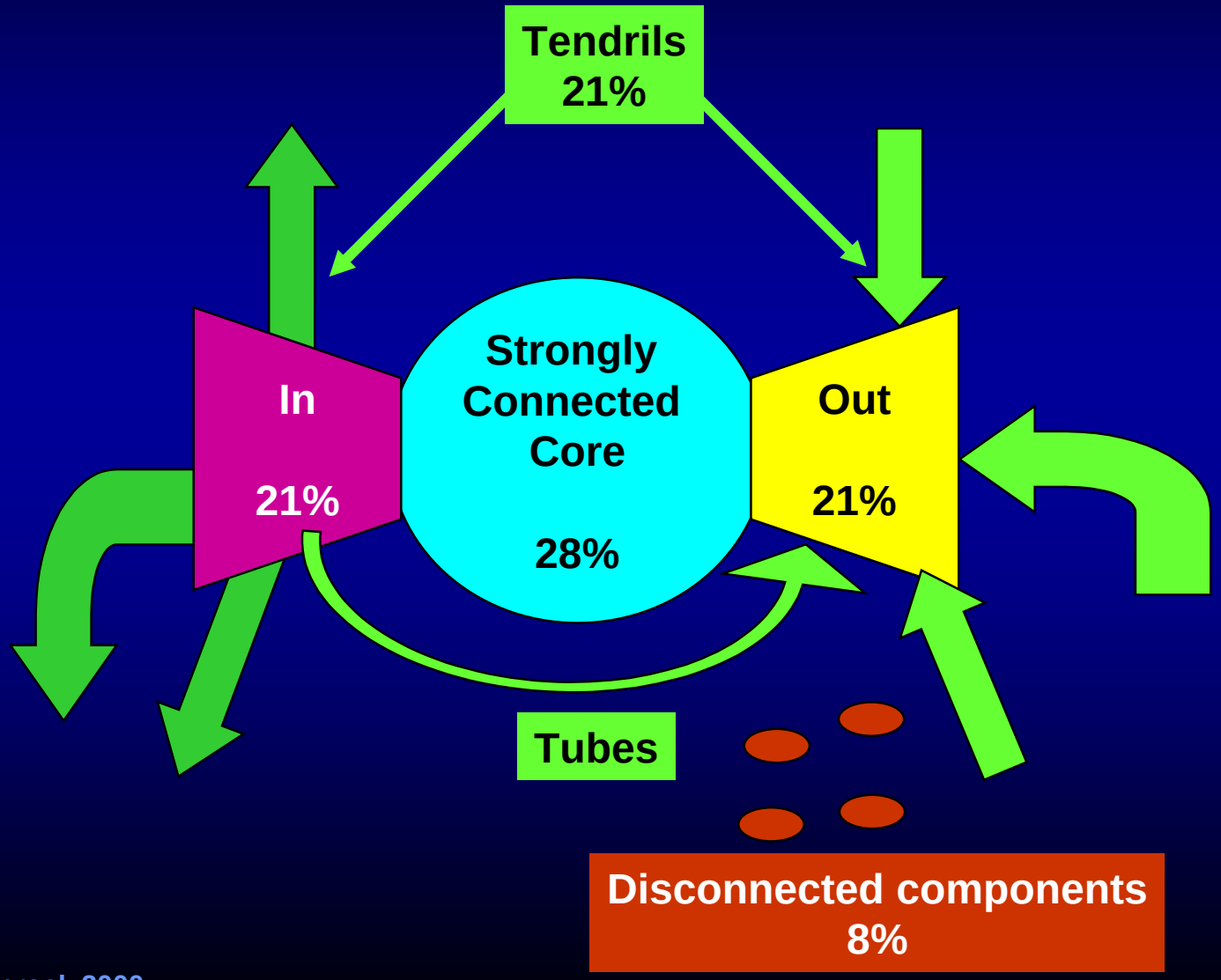


Average distance between web pages is 16
If links were not directional, the distance is 7
That is, 7 degrees of “separation”

But … Is This Really The Structure of the Web?



The Bow Tie Structure of the Web



The Evolution of the Internet

Period	Technology	Access	User Community
The Early Period 1959-1969	Principles of Data Networking	A wasteland	A handful of pioneers
The Birth Period 1969-1972	Packet Switching at 50 Kbps	Weak access via the NCP Protocol	Computer Scientists
The Middle Years 1972-1980	Public networks struggle to survive	Internetworking problems apparent	Email dominates user applications
Internetworking 1980-1990	Mbps networks (WAN & LAN): last mile inadequate	TCP/IP widely deployed	Science community plus a handful of commercial users
Explosion 1990-2000	Gbps networks (WAN & LAN)	Nomadicity adds tremendous complexity to access	Commercial and consumer user population
Future 2000-	Pbps networks. Wireless pervasive Last mile deployed (always on)	Nomadicity deployed	Nomads and Smart Devices

The Vision Has Three Phases

1. **Advanced Network Technology**
   - Gigabit/sec and Petabit/sec networks
   - Wireless everywhere
   - Broadband access networks
2. **Nomadic Computing**
   - Travelling from your office to another location and still having access to your full set of Internet resources
3. **Smart Spaces**
   - Moving the Internet into your physical world

Phase 1:

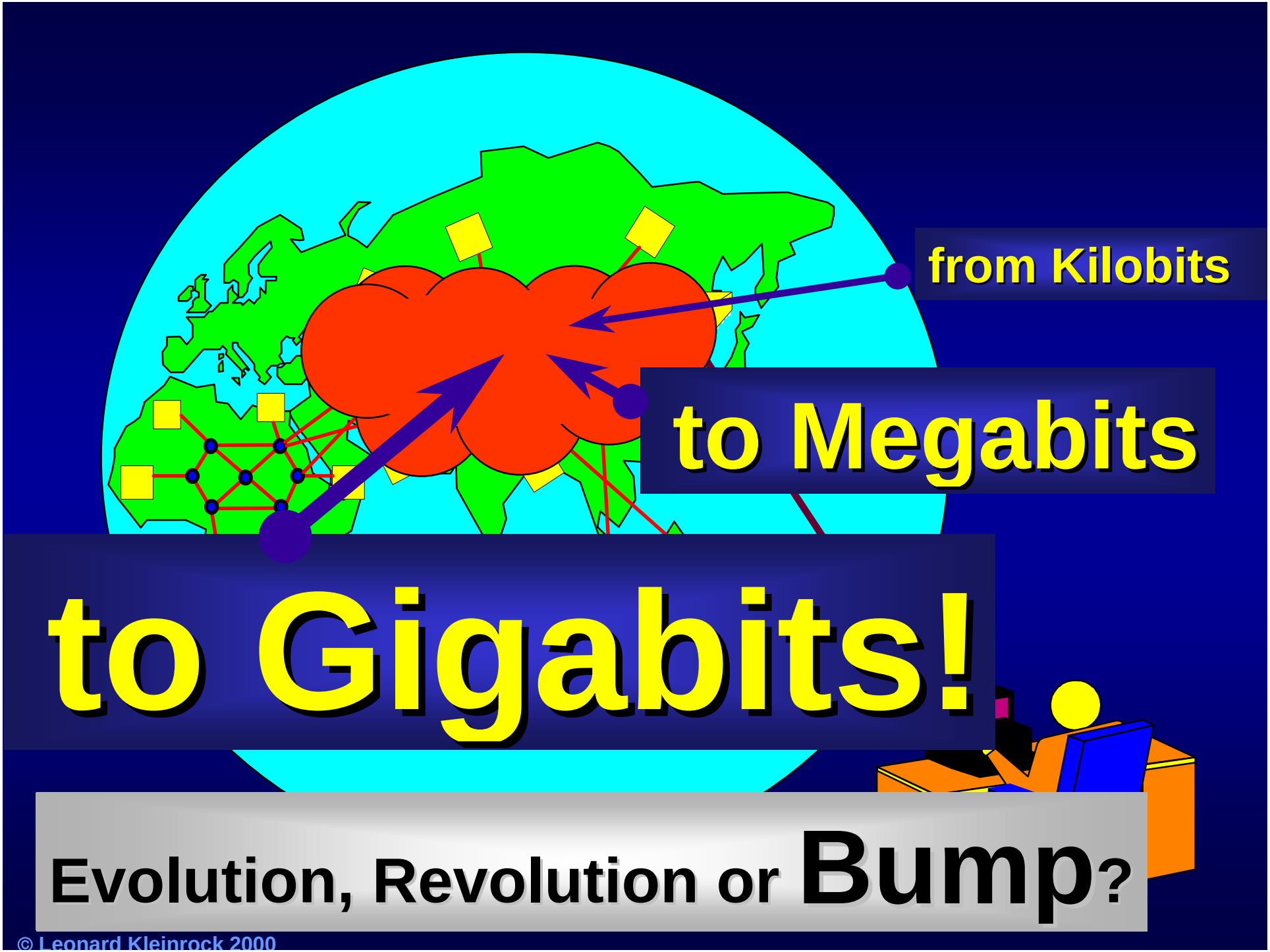
Advanced Network Technology

- Gigabits, Petabits & Latency
- Wireless Access
- Broadband access networks

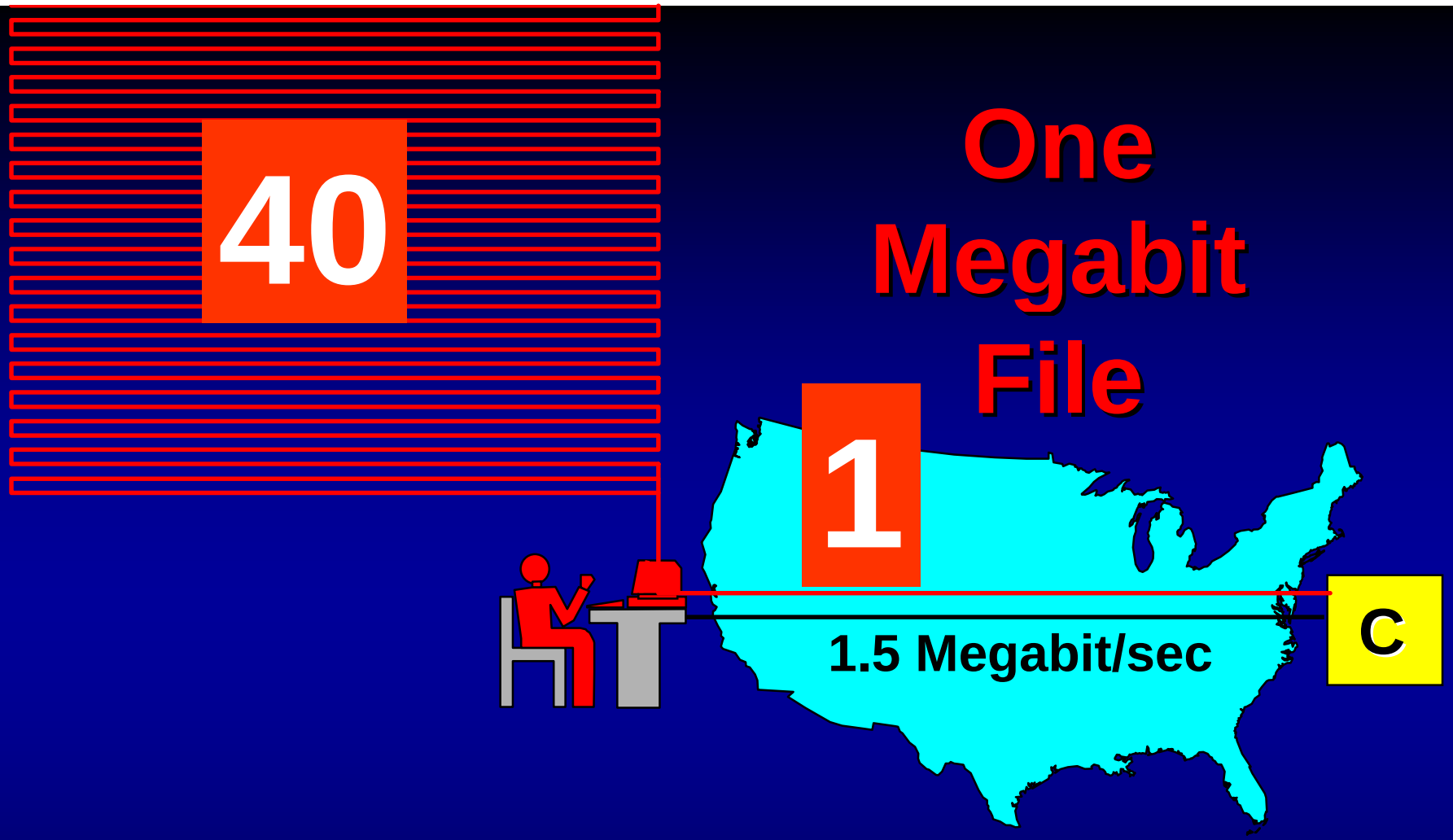
Just how fast is a gigabit?

Fast!

- But ... the speed of light isn't!



One Megabit File

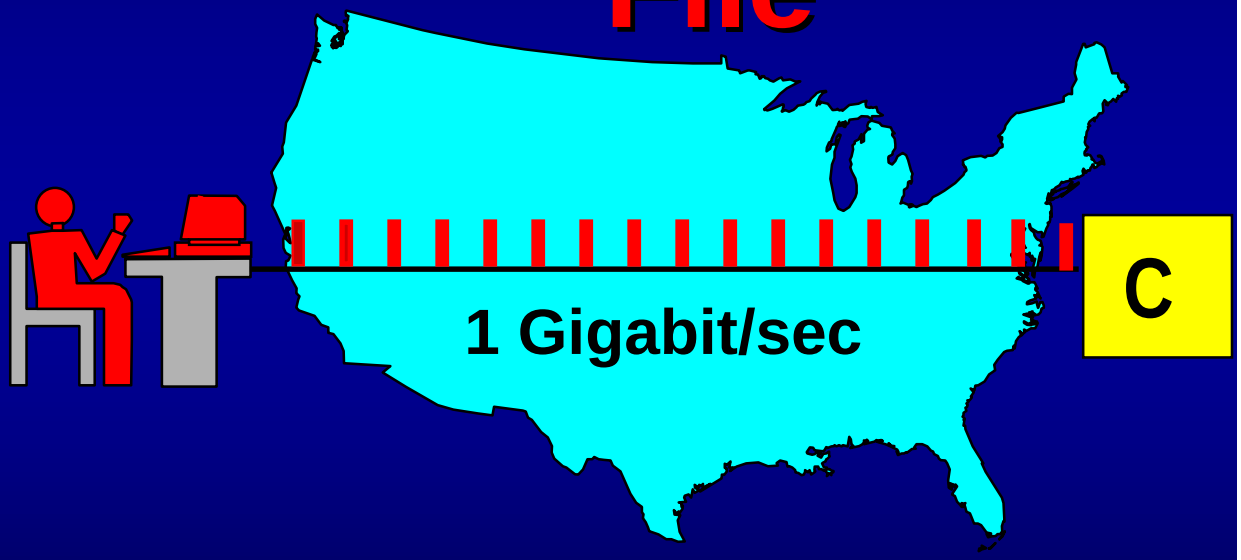


We seem to have bumped into the speed of light!

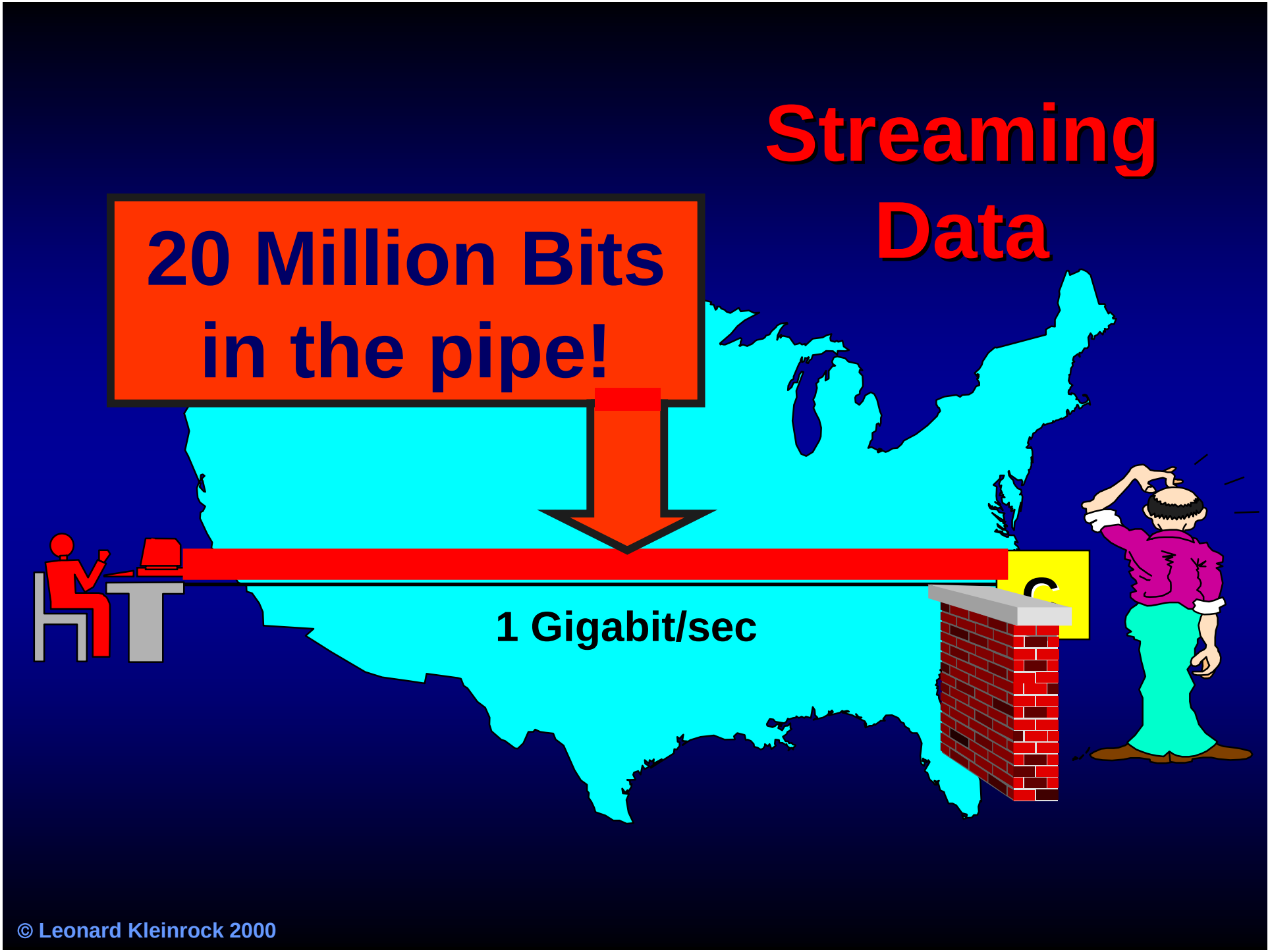
or

Something's going "bump" in the light!

One Megabit File



Streaming Data



Just How Fast is a Petabit/sec?

- Darned fast !

At that speed you can transmit the 20 trillion bytes in the Library of Congress in 1/6 of a sec !

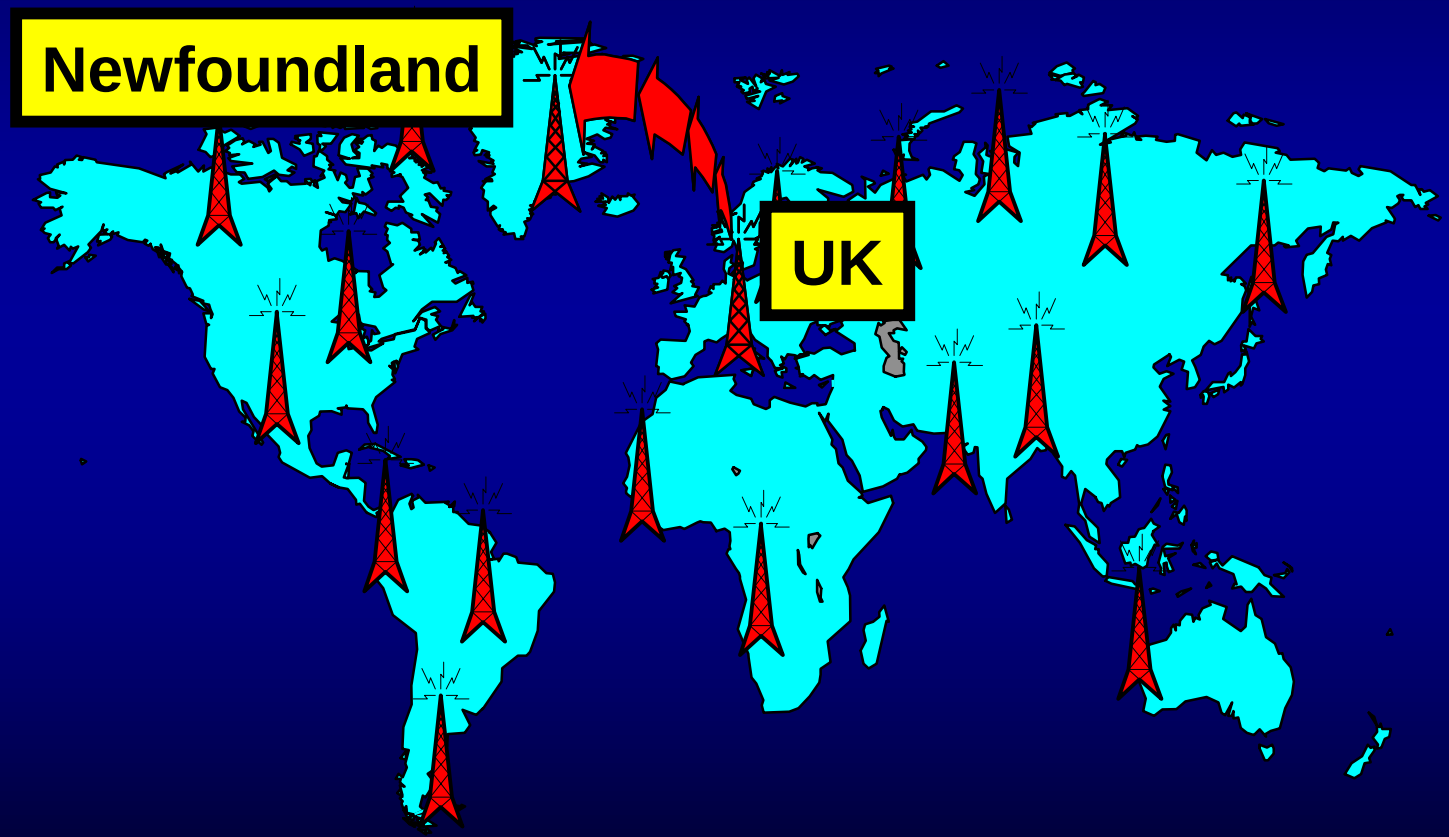
Phase 1:

Advanced Network Technology

- Gigabits, Petabits & Latency
- Wireless Access
- Broadband access networks

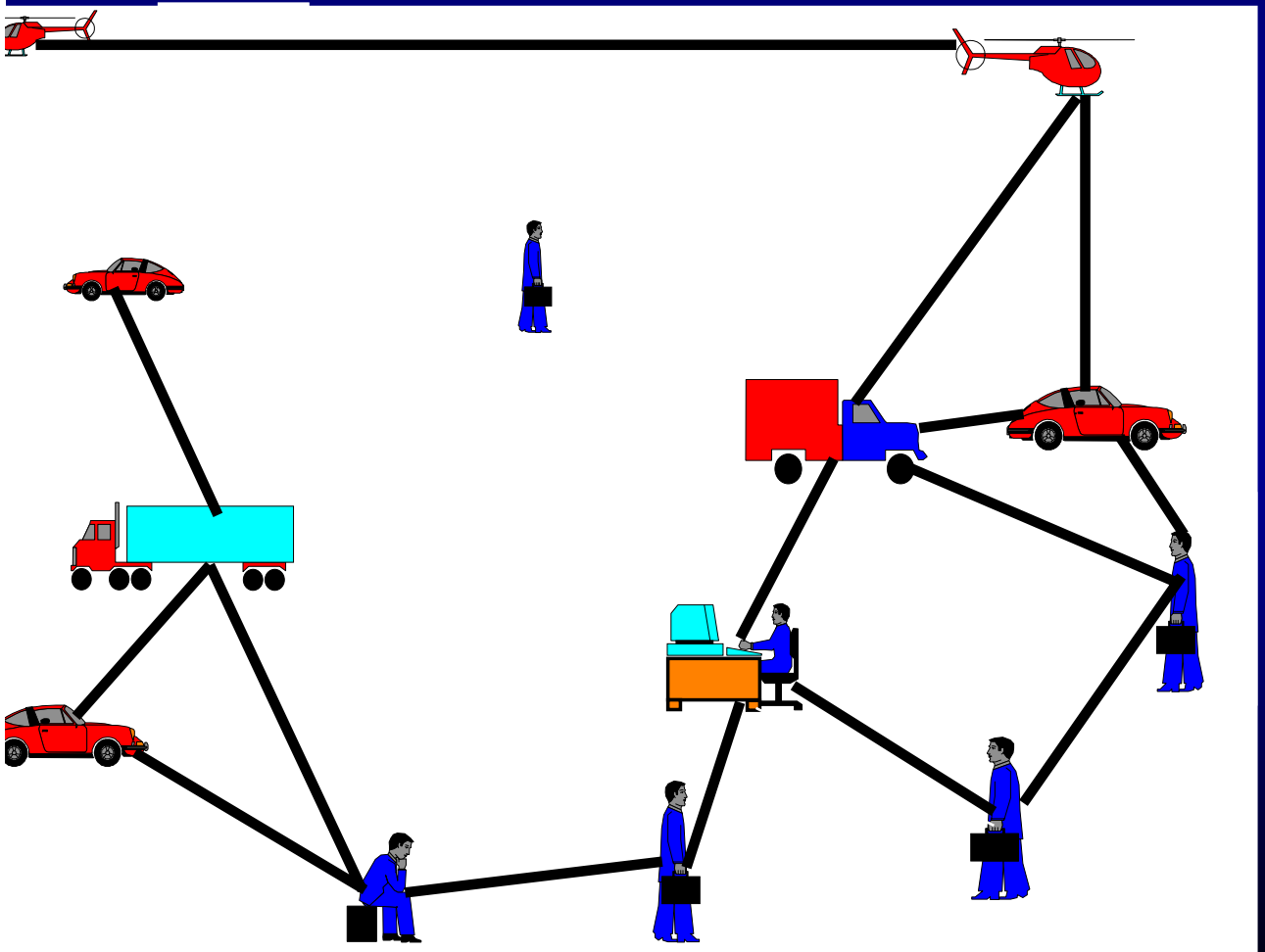
A Brief History of Radio

- Guglielmo Marconi : 1901



A Brief History of Pkt Radio

- 1970's: ARPA



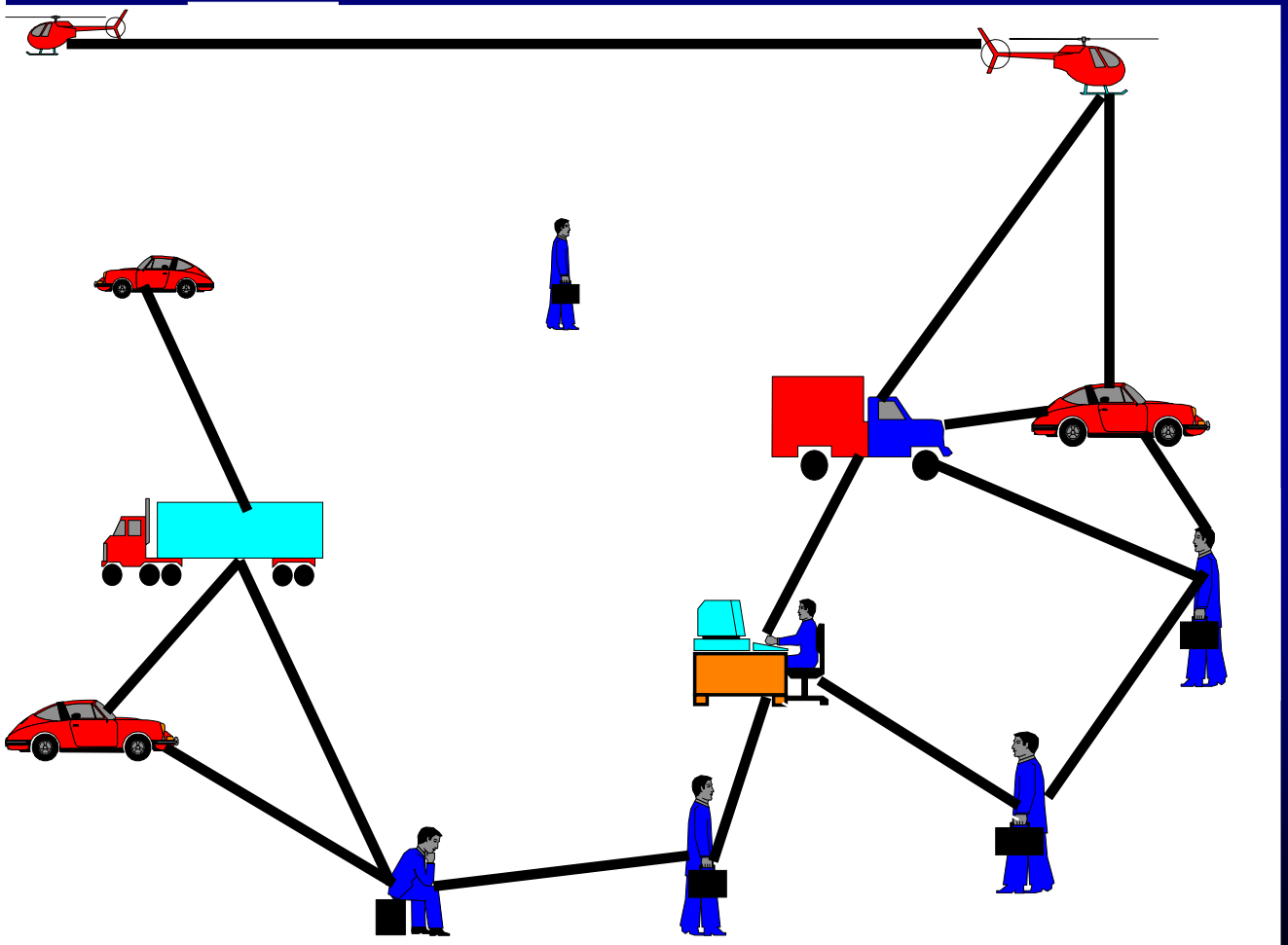
250 cu in

25 watts

25 lbs

A Brief History of Pkt Radio

- 1970's >> 1990's: ARPA



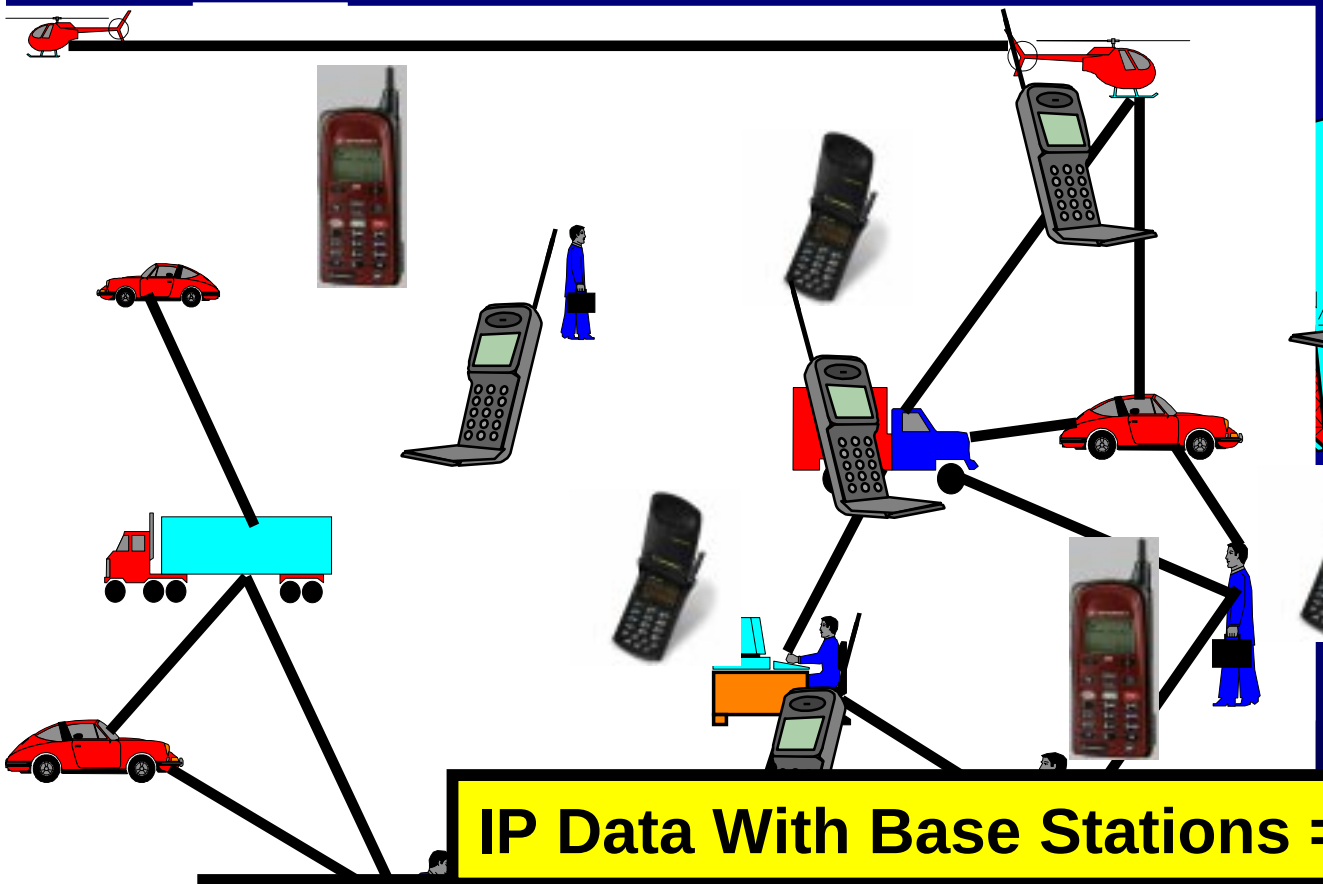
250 >>10 cu in

25 >> 1 watt

25 >> 1 lb

A Brief History of Radio

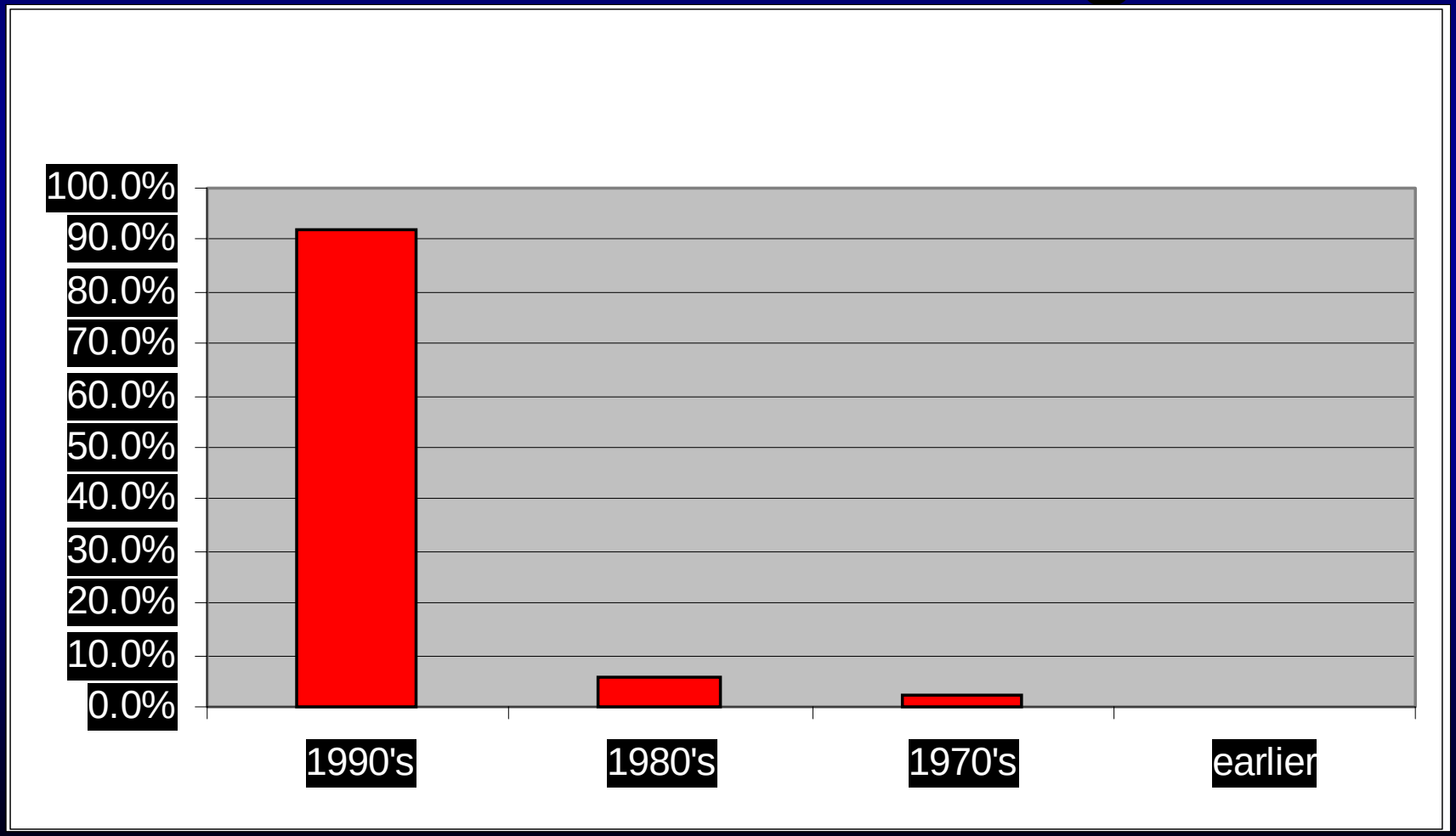
- 1970's >> 1990's: ARPA >> MobiHOC: 2000



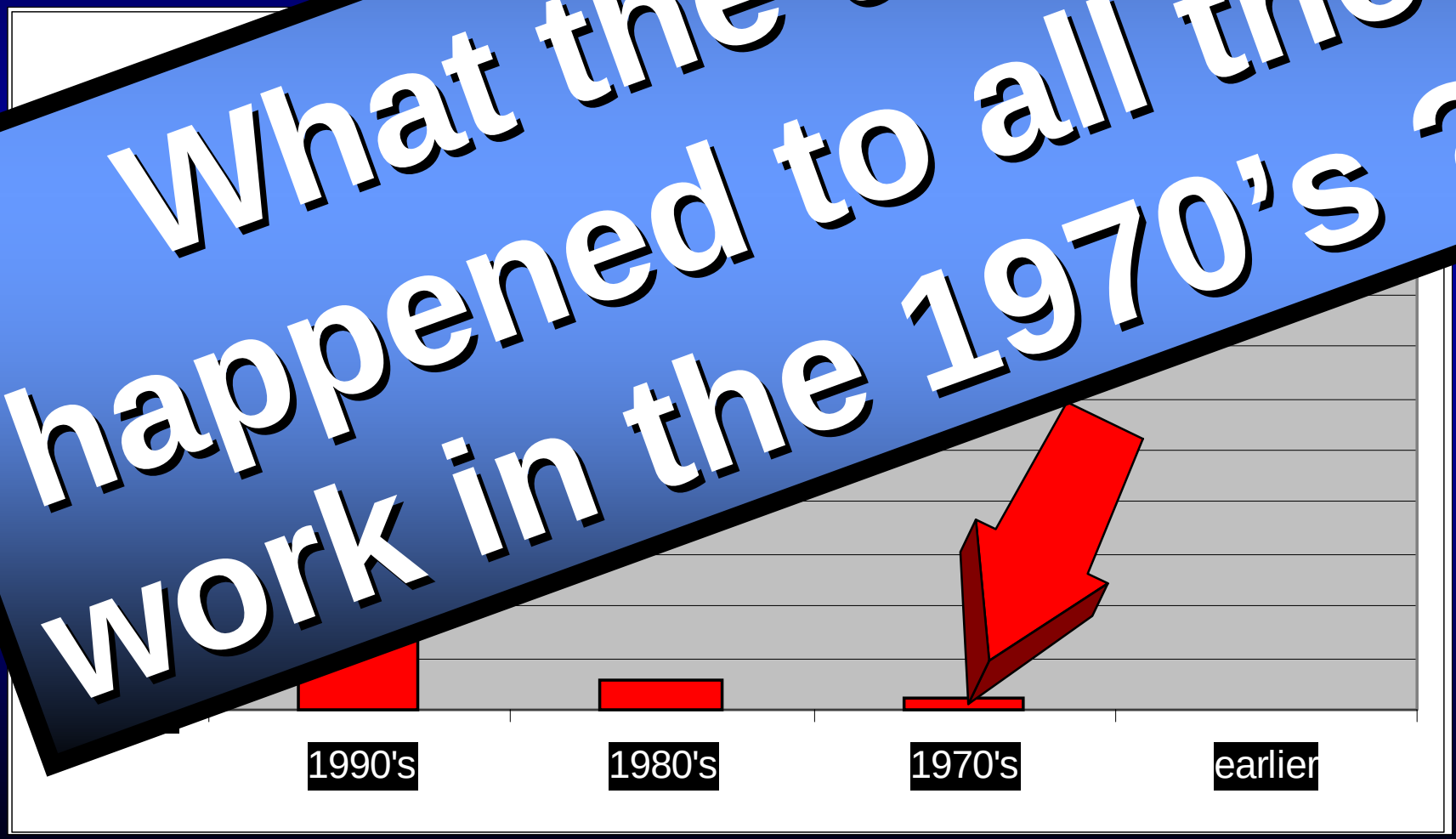
IP Data With Base Stations = 3G

IP Data Without Base Stations = Ad Hoc Multihop

The Papers at Mobicom had 573 Reference Listings



The Papers at M… …'73 Ref…



What the devil happened to all the work in the 1970's ?

The Papers at Mobicom had 573 Reference Listings

- 92 % were from 1990-2000
- 6.5% were from the 1980's
- 1 % were from the 1970's (i.e. 5 references)
  - 1979 one on Visual Perception
  - 1978 one on Monte Carlo Methods and one on distributed processes
  - 1975-6 three references to my books
- 0.5% from earlier:
  - 1969 one on geographical variation statistics
  - 1957 one on radio propagation
  - 1952 one by Turing on the chemical basis of morphogenesis

The Papers at MobiHOC had 219 Reference Listings

92 • 92 % were from 1990-2000

5.5 • 6.5% were from the 1980's

2.5 • 1 % were from the 1970's (i.e. 5 references)

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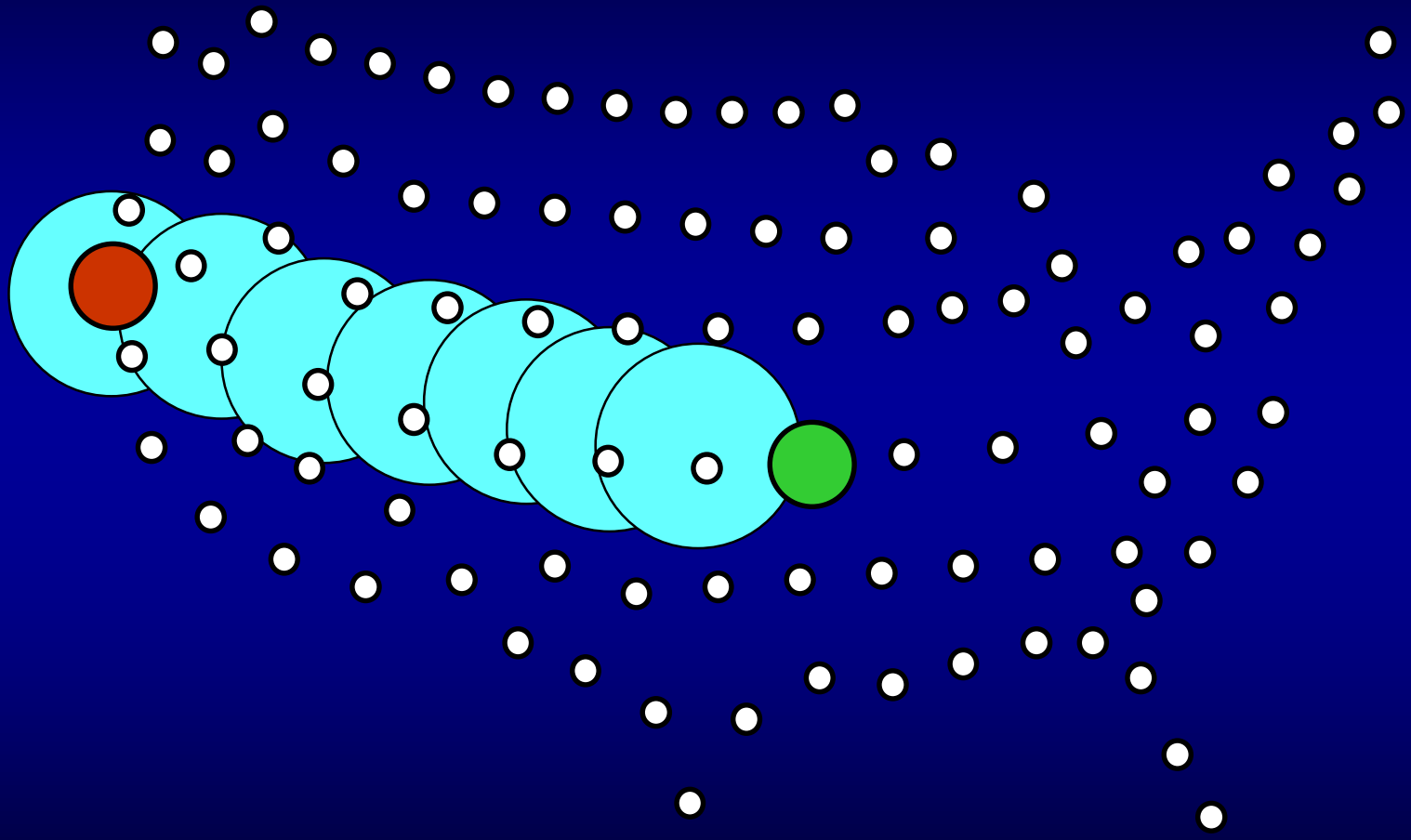
Giant Stepping
in Packet Radio

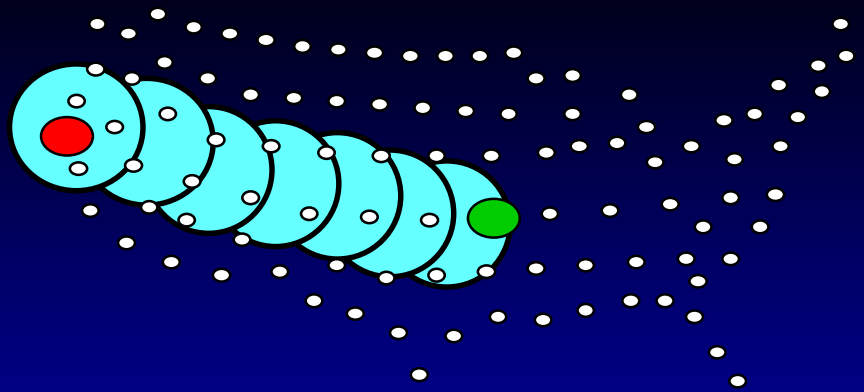


L. Kleinrock, "On Giant Stepping in Packet Radio Networks,", UCLA, Packet Radio Temporary Note #5 , PRT 136, March 1975.

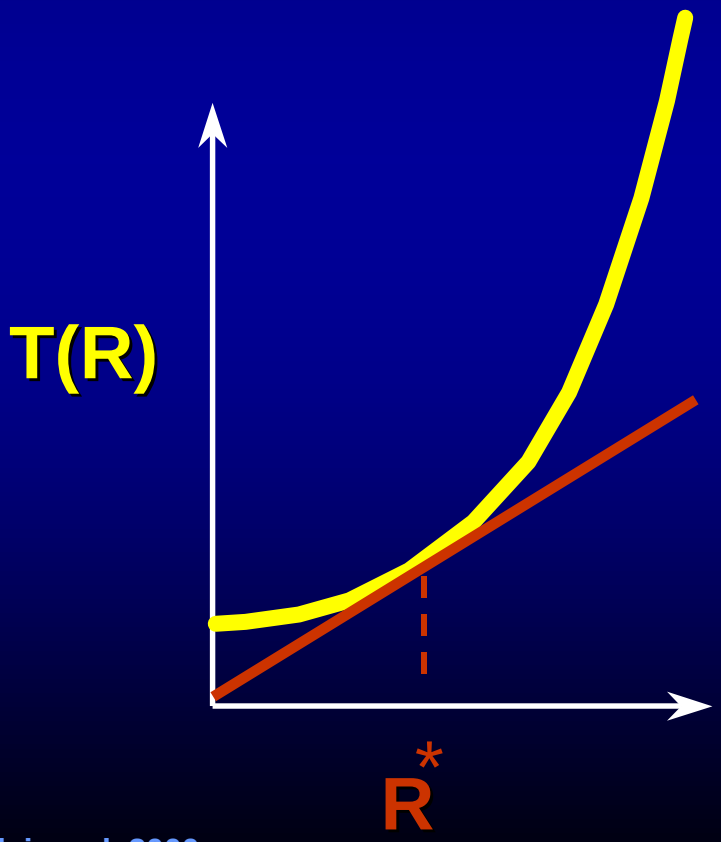
Giant Stepping
in Packet Radio

- 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
- T(R) is mean response time per hop
- Total Delay = T(R)[D/R]
- Choose $R=R^*$ to minimize total delay
- dT(R)/dR = T(R)/R optimality condition

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



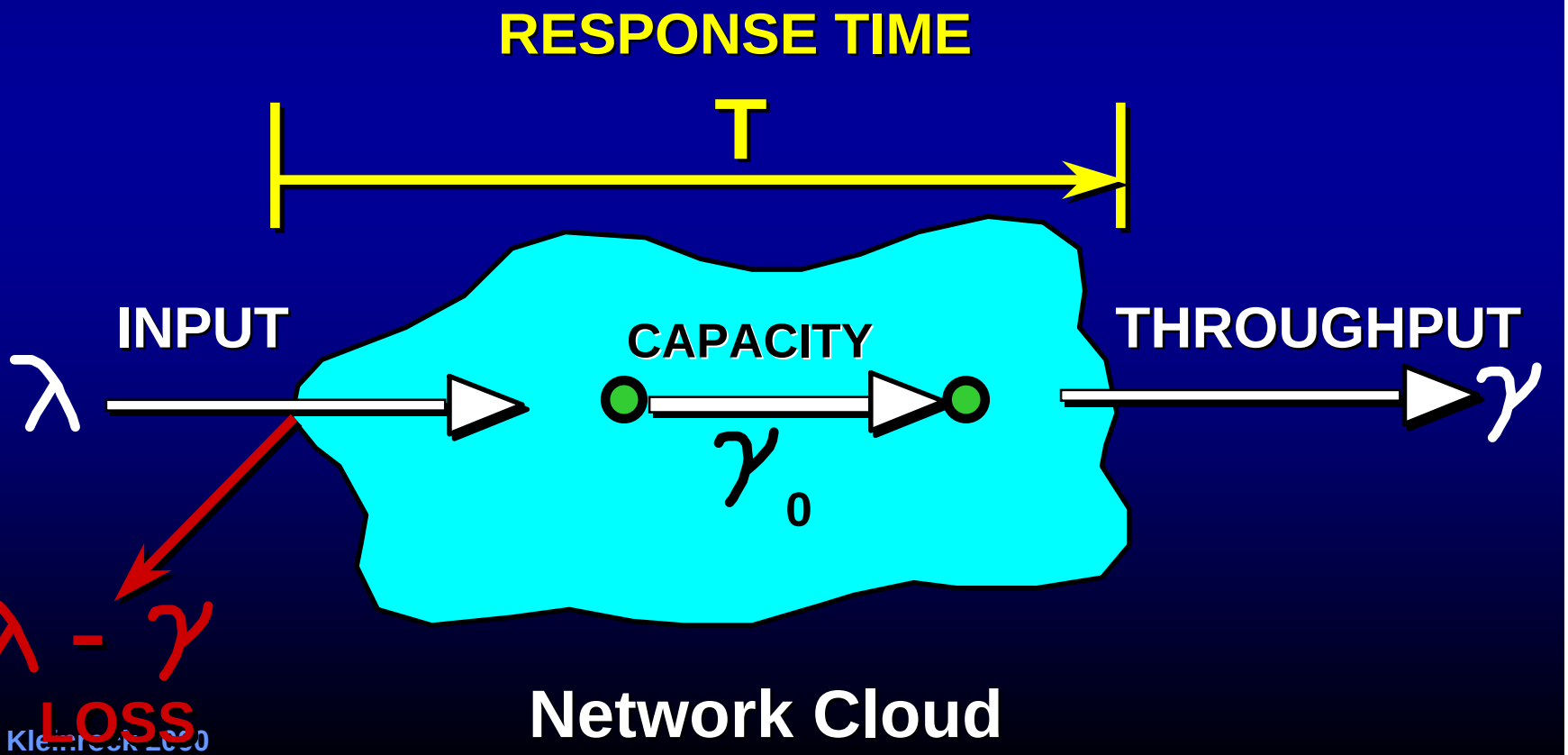
$$dT(R)/dR = T/R$$



This is the optimal radius
Independent of access method
Independent of arrival process
Independent of pkt size distribution
etc.

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

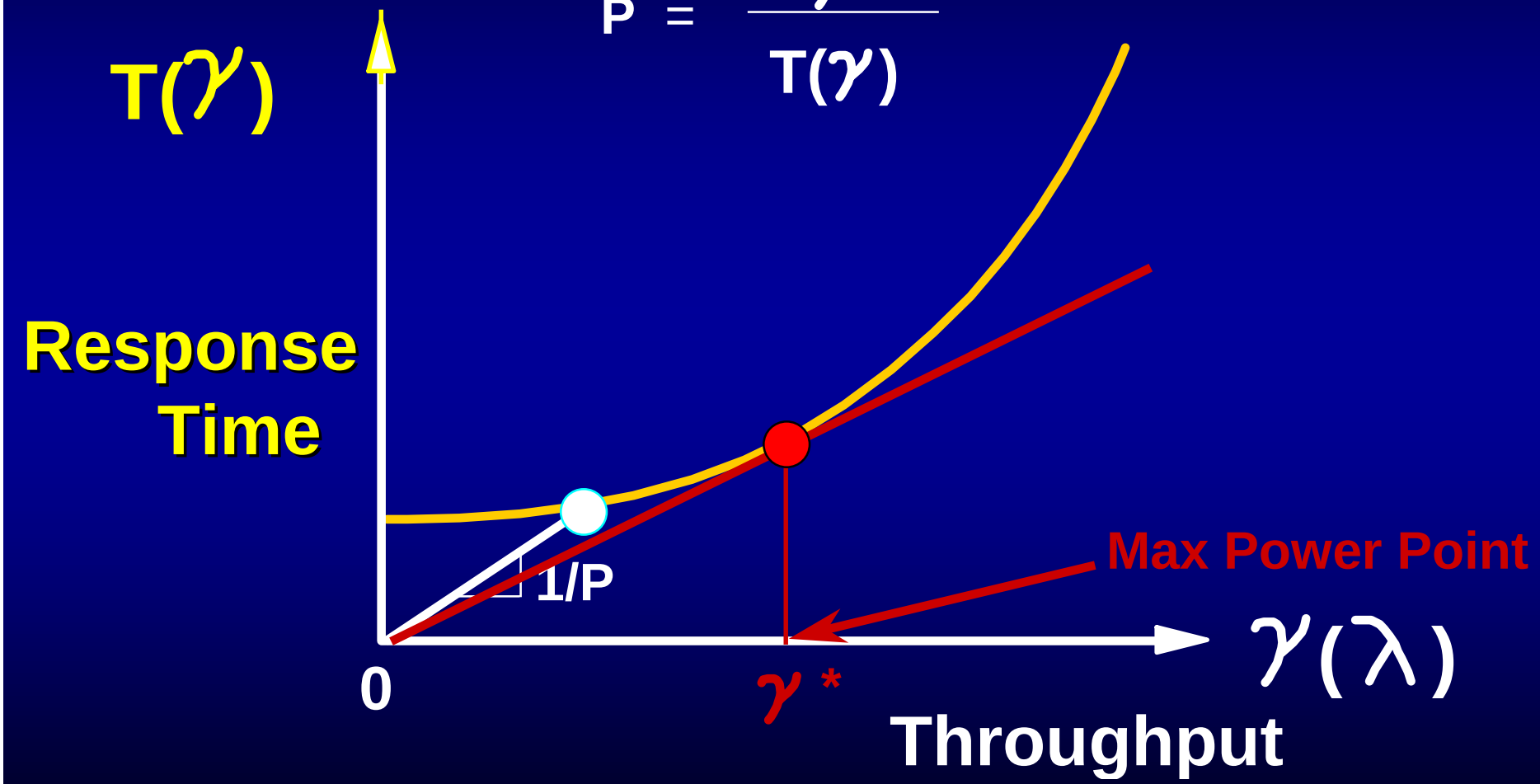
Response Time
Throughput
Loss



Response Time vs Throughput

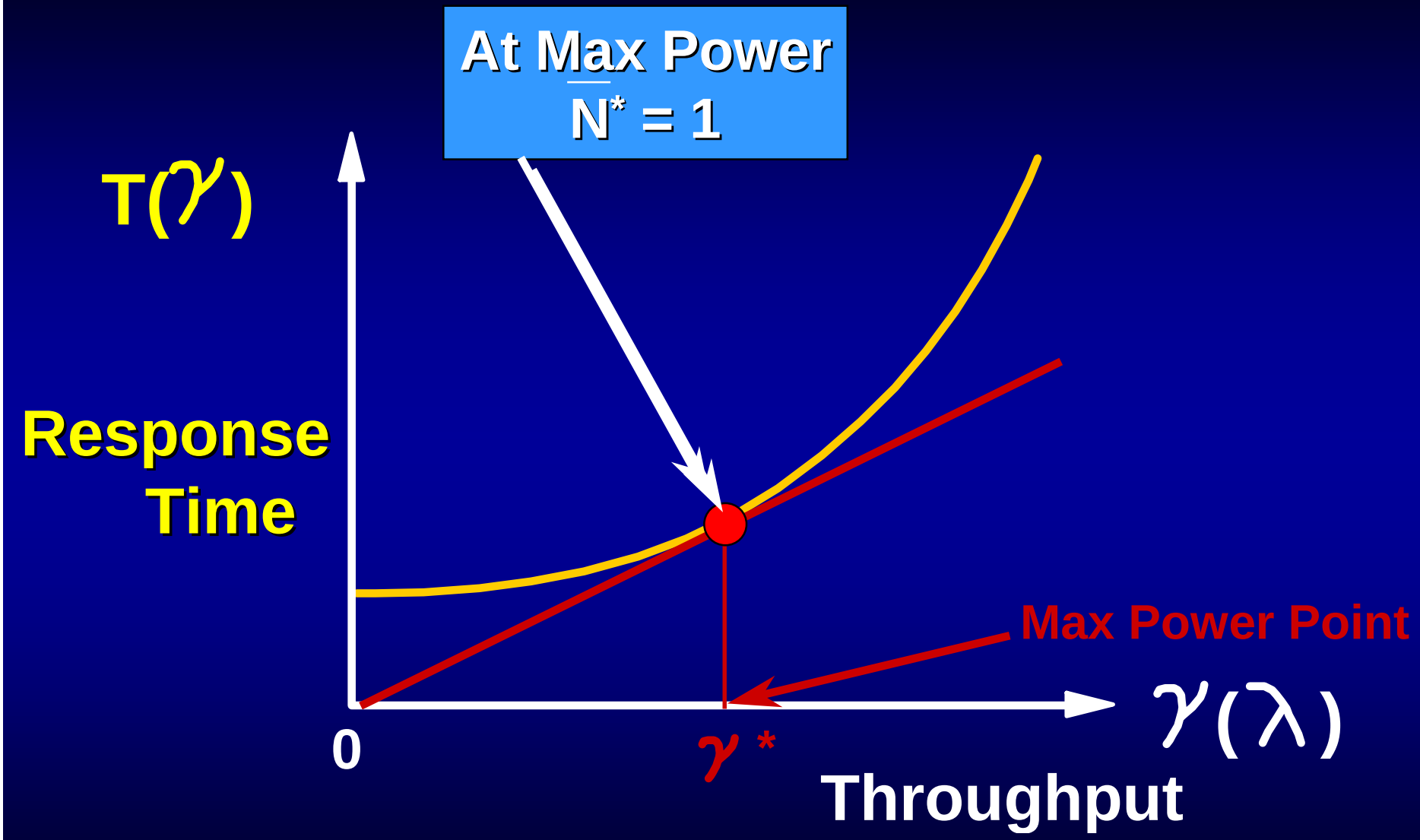
$$\text{POWER} = \frac{\text{Throughput}}{\text{Response Time}}$$

$$P = \frac{\gamma}{T(\gamma)}$$



Kleinrock, L., "Power and Deterministic Rules of Thumb for Probabilistic Problems in Computer Communications", Conference Record, International Conference on Communications, Boston, Massachusetts, pp. 43.1.1 to 43.1.10, June 1979.

Response Time vs Throughput



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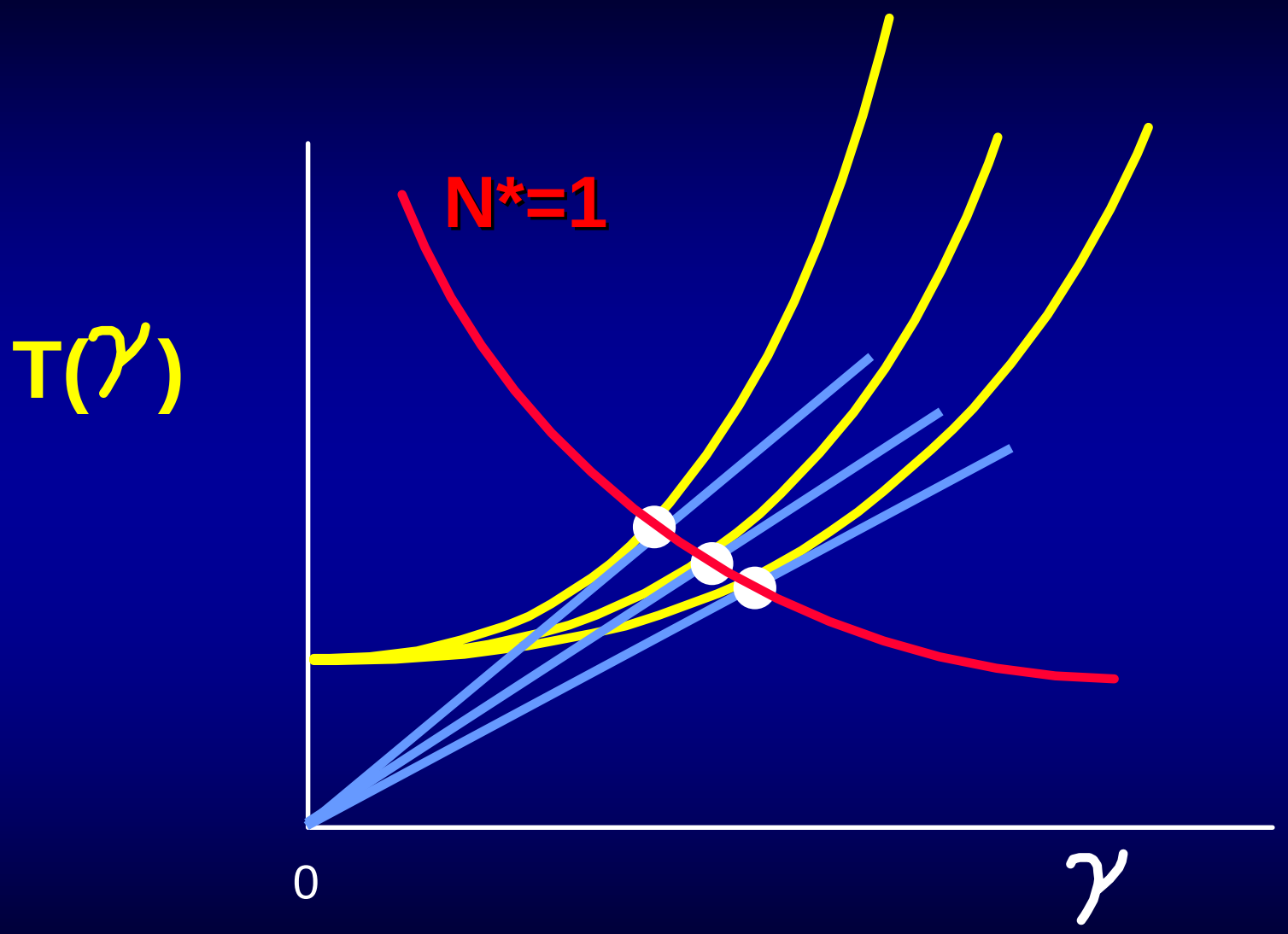

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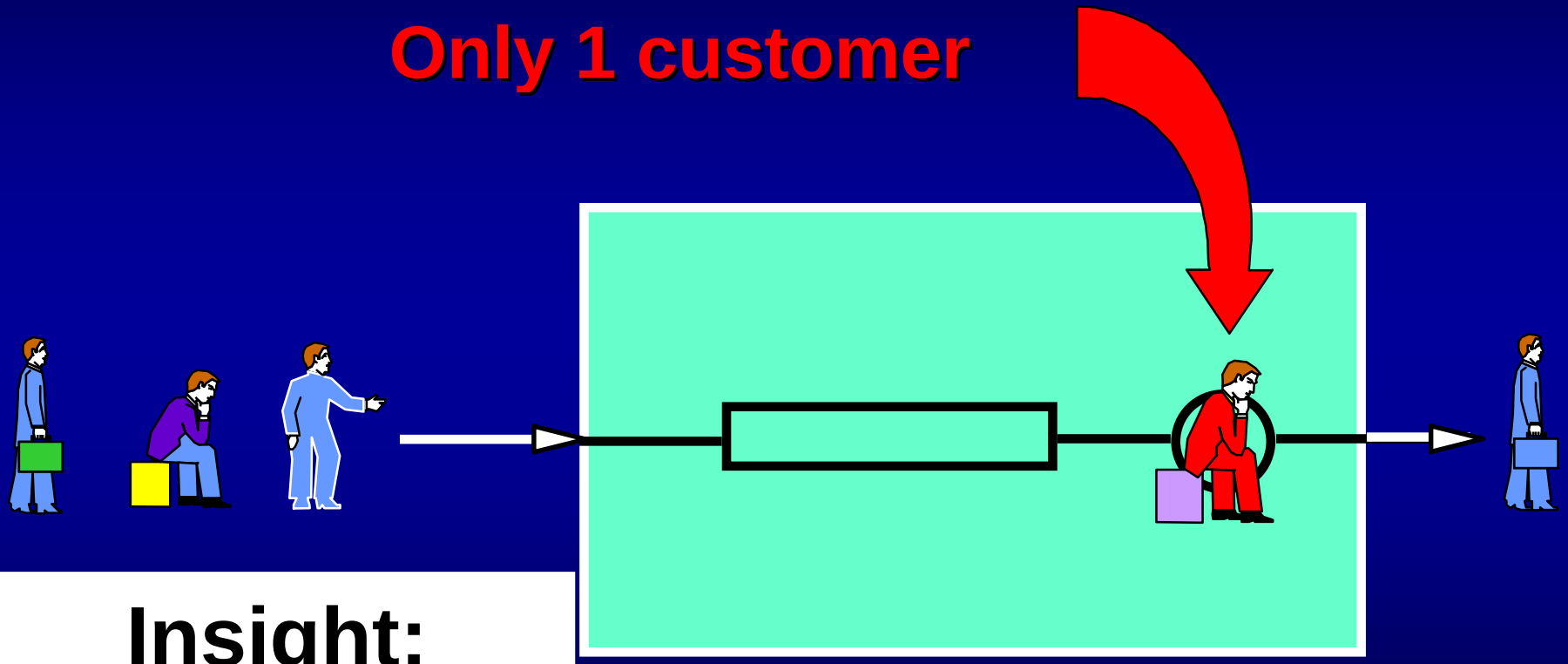
Use Your Intuition

Only 1 customer



Insight:
Just keep the pipe full!

T = Min
Eff = Max

What's Missing In Your Research?

- You need to devote some of your research to larger issues, to more analysis, to basics.
- How about invariances?
- How about fundamental tradeoffs?
- How about global behavior?
- How about asymptotics?
- How about effects that emerge in **really large networks**?
  - Dynamics
  - Oscillations
  - Instabilities
  - Traffic storms
  - Continuum of nodes

From Theory to Practice

A 1964 Lesson From Dan Heyman

- Fire station location problem
- Optimum solution
- But …

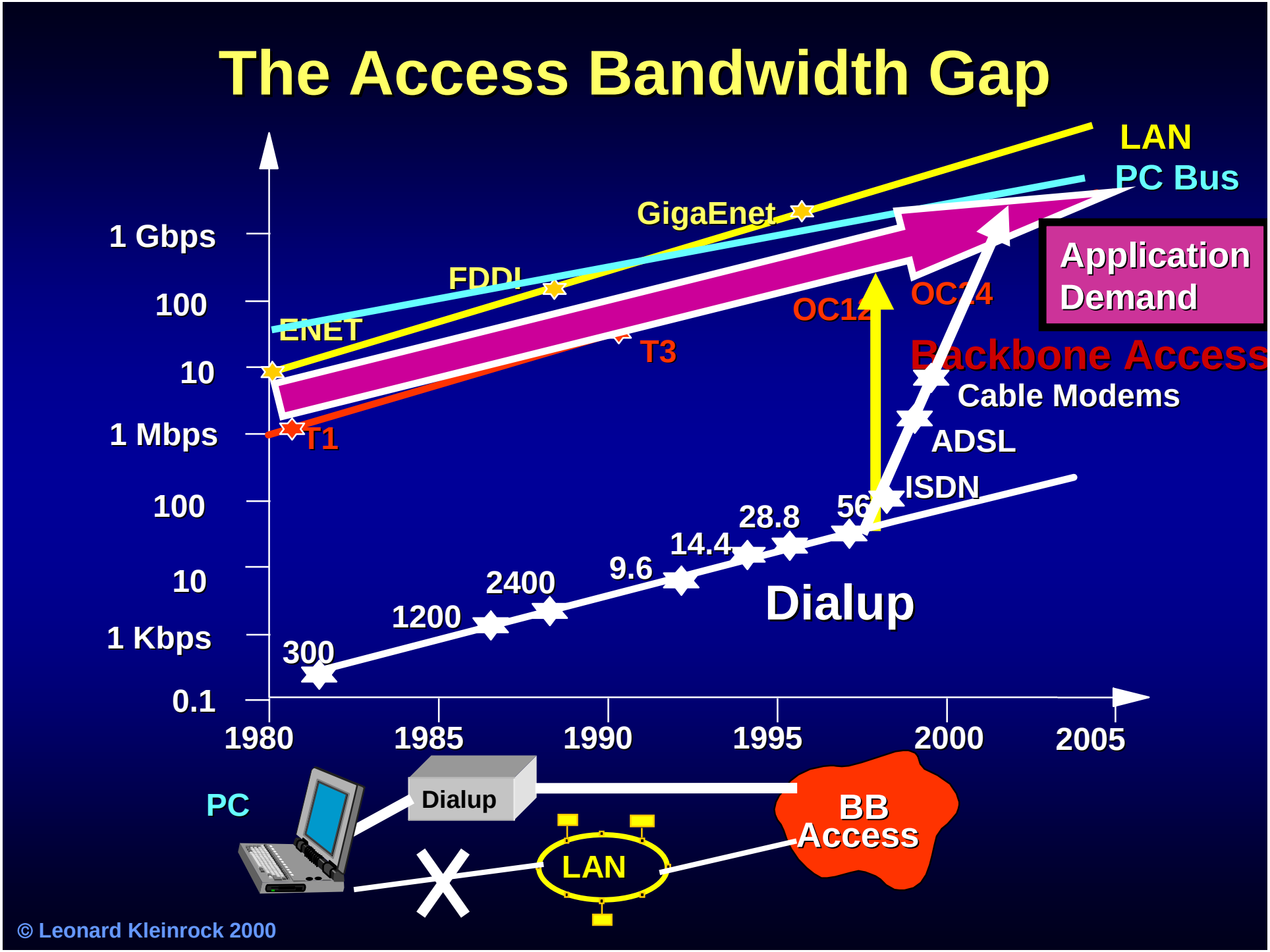
  … one day he visited the forest!

Phase 1:

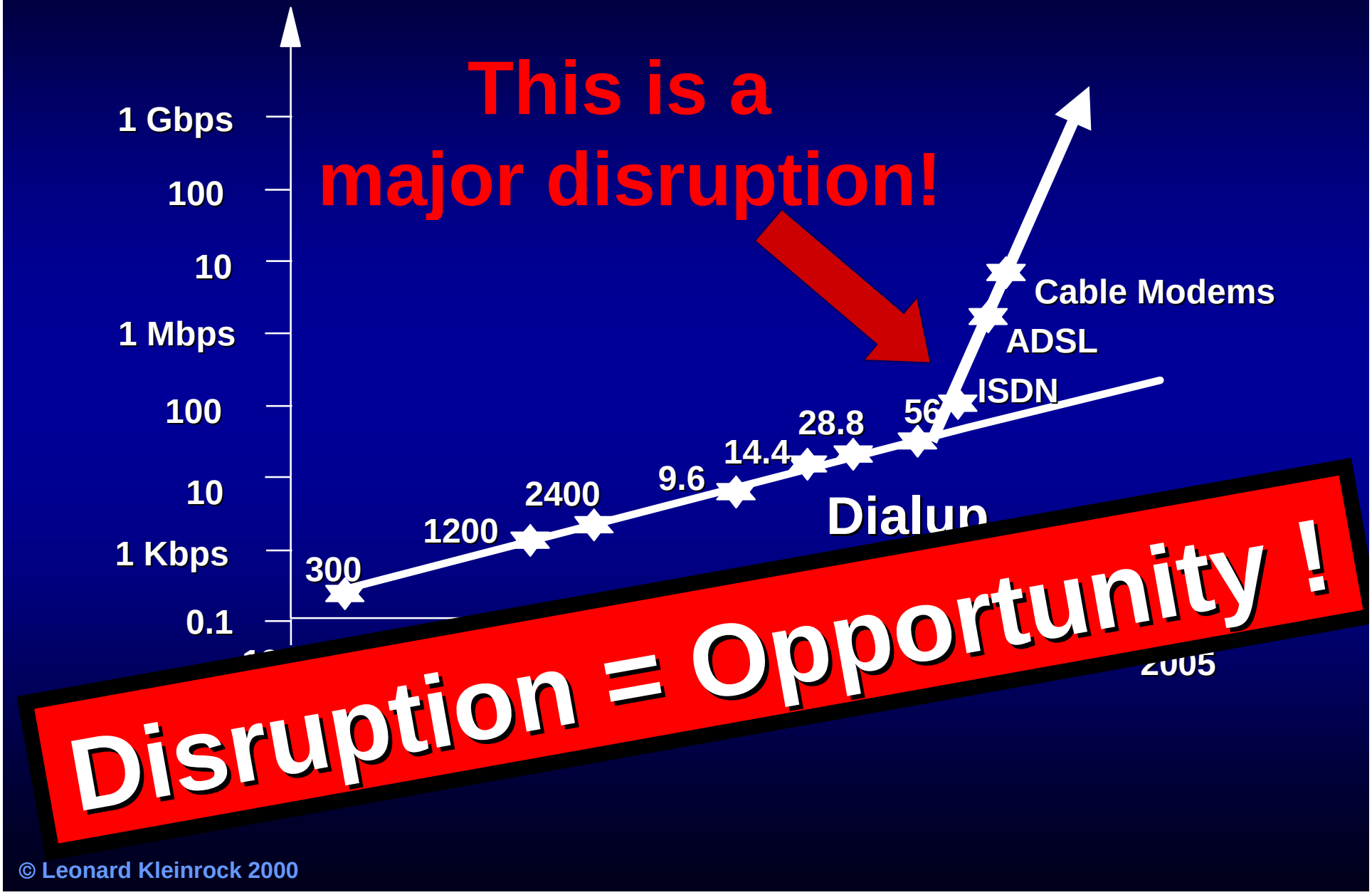
Advanced Network Technology

- Gigabits, Petabits & Latency
- Wireless Access
- Broadband access networks

The Access Bandwidth Gap



The Access Bandwidth Gap



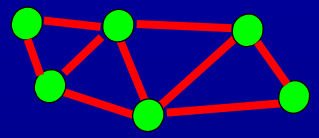
Phase 2:
Nomadic Computing

Travelling from your office to another location and still having access to your full set of Internet resources

In Your Office You Have ...

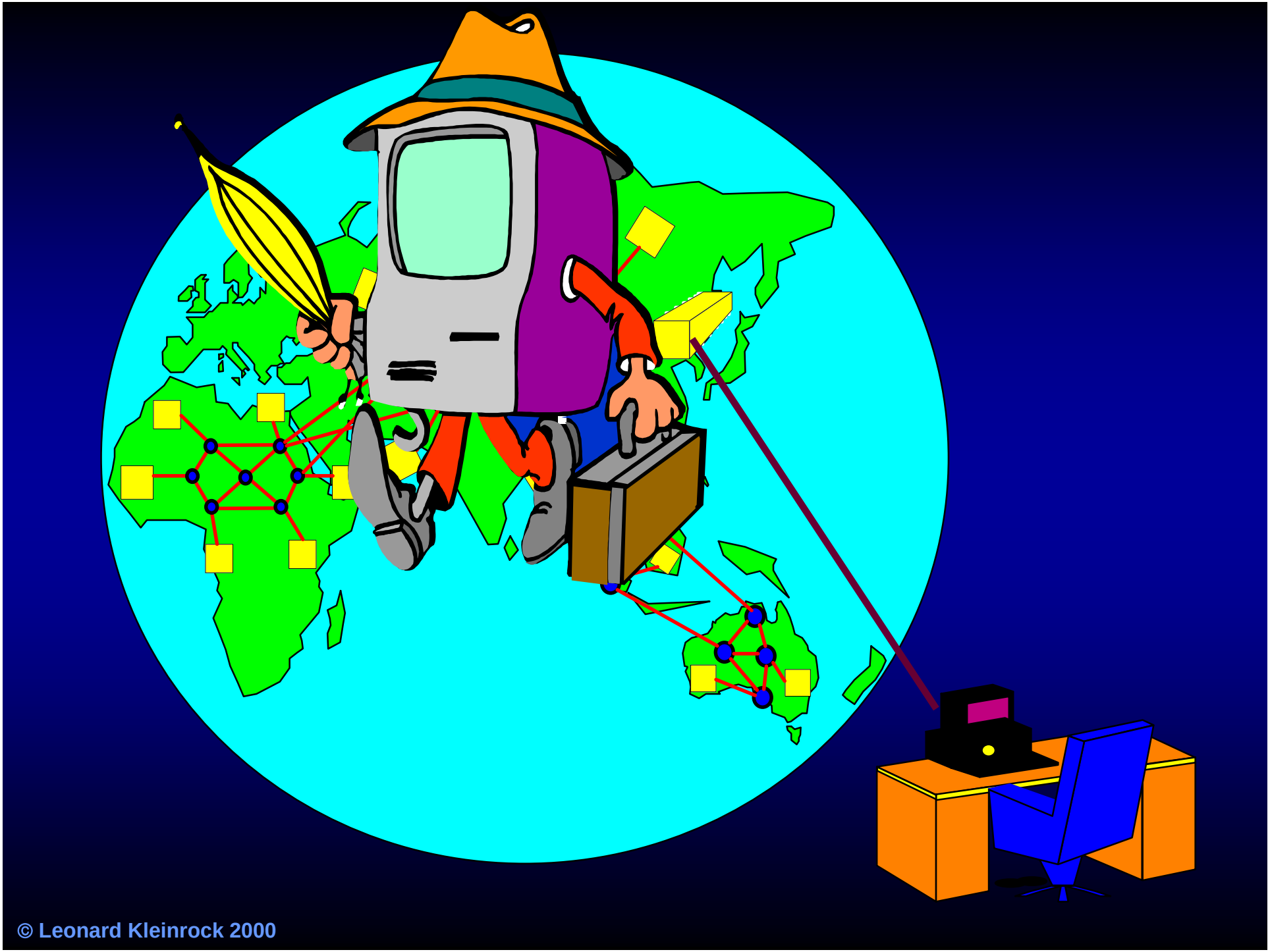
- A High performance workstation

- Access to high speed networks

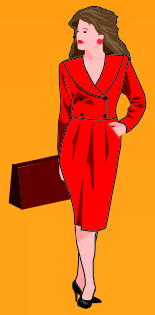


- Support from an IT Systems Administrator

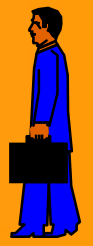
You lose the last 2 as soon as you go on the road !


© Leonard Kleinrock 2000

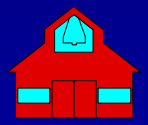
On the Move



Enter the Nomads!



Where Nomads Travel



Office

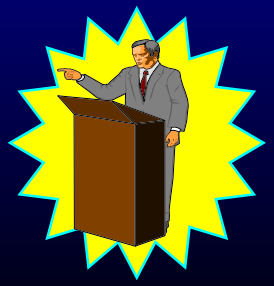
Home

Airplane

Hotel

Automobile

Branch Office



Bedroom

Here at MobiHOC !

On The Road

I travel with a

- Scientific calculator watch
- 2-way email pager
- Palm Pilot
- Cell phone
- Notebook computer

This is Ridiculous!

That means I carry

- 5 displays,
- 5 keyboards,
- 5 speakers,
- 2 microphones,
- 5 clocks,
- 5 batteries,
- 4 data bases,
- 4 communication devices.

This garbage is:

- Strapped to my waist
- Lugged in my briefcase
- Unique awkward interfaces
- Horrible battery life, all different batteries
- Lilliputian keyboards
- Eye-straining screens
- Missing modular attachments
- Vendors' curse of non-interoperability

- **Velchro integration**

Nomadic Attributes

- Size
- Weight
- Processing power
- Battery life
- Mobile communications
- Interference
- Loss
- Theft (the airport scam)
- Damage (the “Laptop Reflex”)

Nomadicity Exacerbates

- Disconnectedness
- Variable connectivity:
  unpredictable and voluntary
- Variable latency
- Variable requirements
- Resource replication
- Security
- Privacy

Nomadicity Exacerbates
(cont)

- Awareness of environment by the user
  - "environment discovery"
- Awareness of user by the environment
  - "user discovery"
- Adaptivity/compression to match bandwidth and platform capability

- Management of distributed "stuff" !

Who Am I?
(or, what identifies me?)

- My PC (or other computing device)?
- My telephone (or other communication device)?
- My desk (or some other location)?
- My ID or address?

Me!

Change Your View

- **The Conventional View:**
  - Radical changes in bandwidth
  - Disconnections
  - Radical changes in latency
  - Deferred operations

Failures or Exceptions!

- **The Nomadic View:**

This is the Usual Case!

The Vision of Nomadicity

To enhance the next generation Internet

so that users will gain ubiquitous access and service transparently, and remove the complexity of networking from the user

Where are the Bottlenecks?

Lots of Places !

- Intermittent connectivity
- Slow links
- Latency all over the place
- Network protocols
- Application protocols
- Other kinds of handshaking
- Protocol conversion
- Sluggish and/or confused network flow control
- Workstation I/O limitations
- Graphic and video cards
- Updating stale data

Optimal Update Times for Out-of-Date Information

- **Problem:**

  When and how often should a user update a given piece of information as it goes further and further out-of-date?

- **Assumptions:**

  There is a **cost C>0** of updating a given piece of information

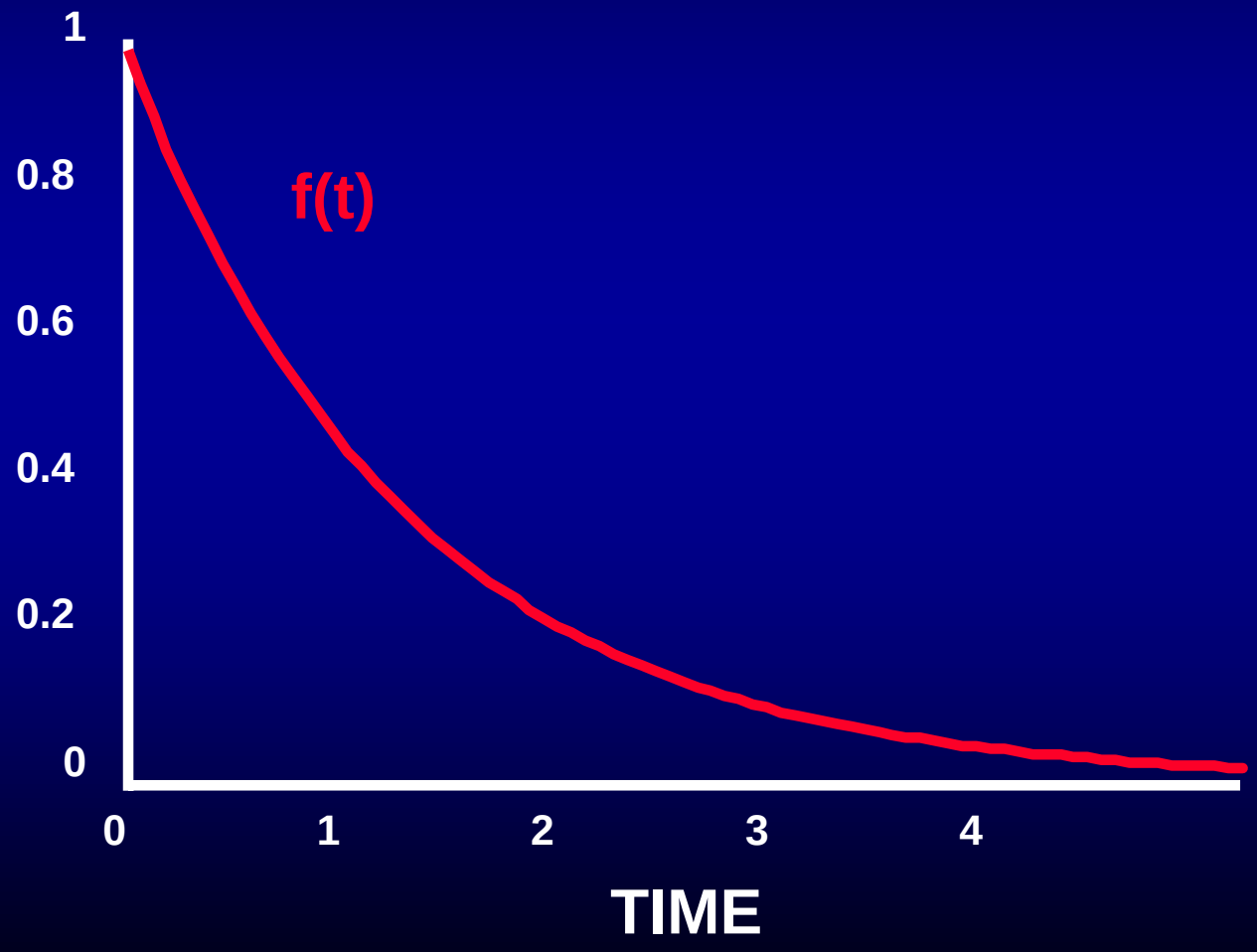
  There is an expected value per unit time associated with having a piece of information that was updated t time units ago.

  - **This value is f(t).**

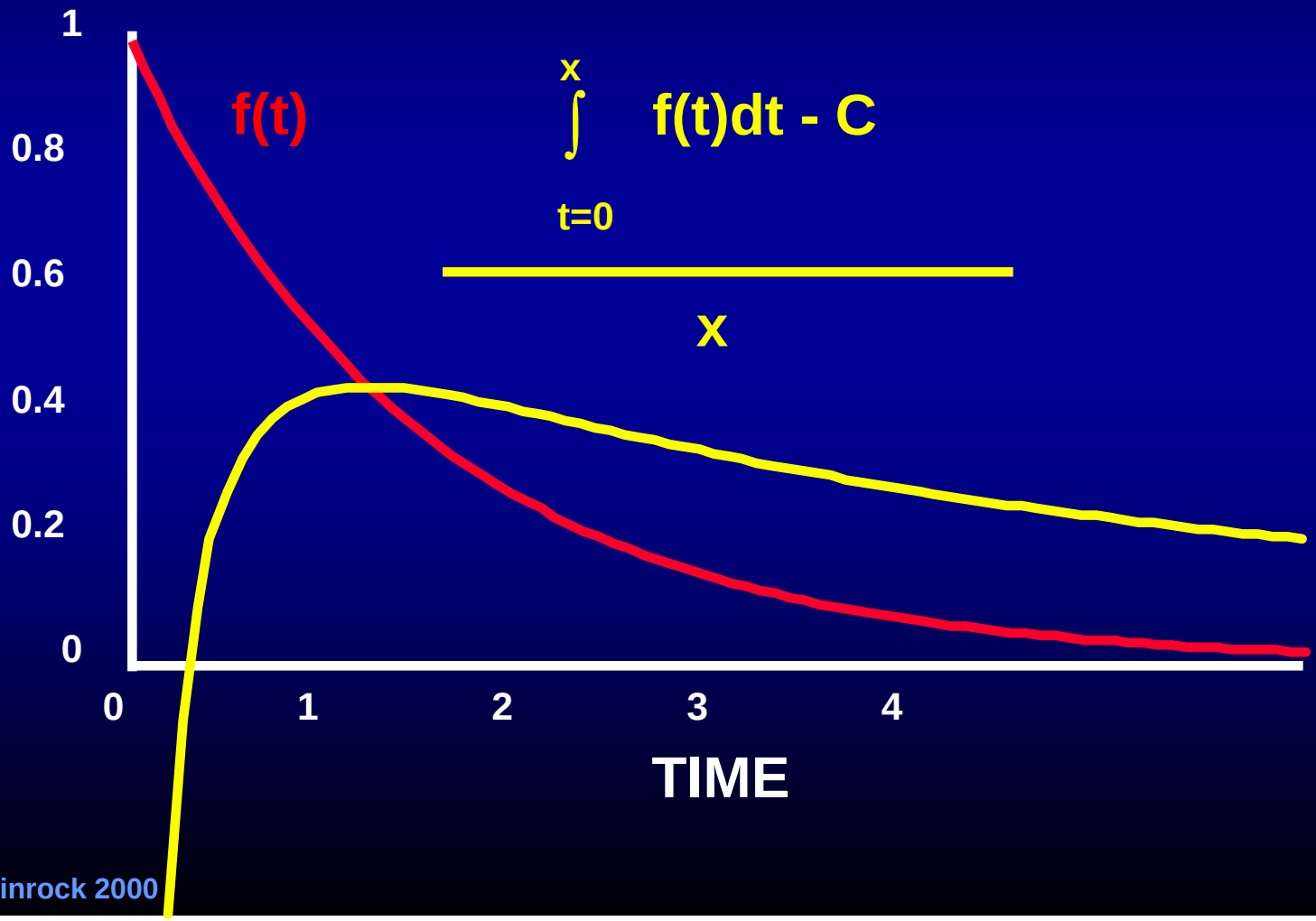
- **Question:**

  Given f(t) and C, When and how often should a user update a given piece of information?

Value of Out-of-Date Information

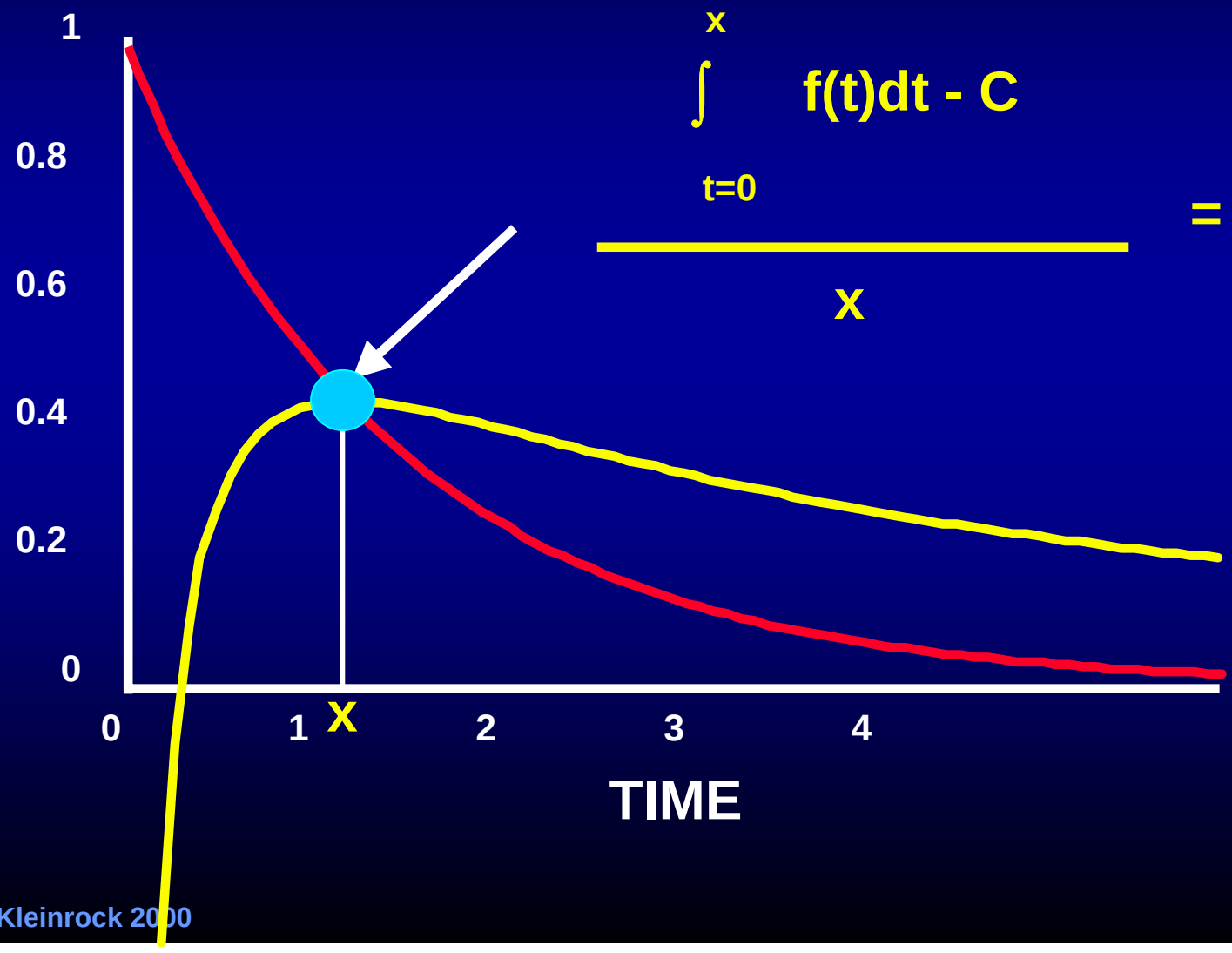


Average Value Gained per Unit Time

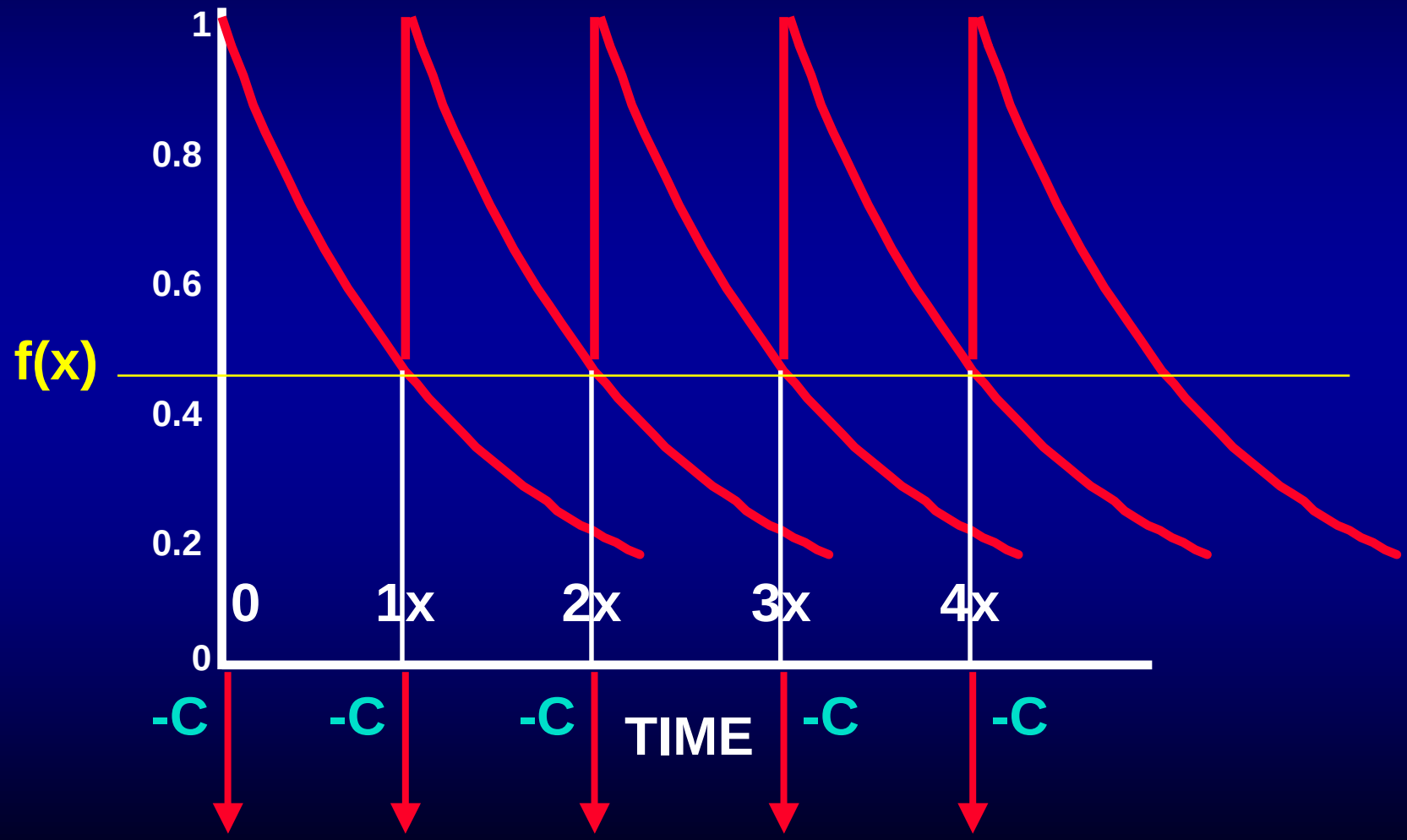


Average Value Gained per Unit Time is a maximum when:

$$\frac{\int_{t=0}^{x} f(t)dt - C}{x} = f(x)$$



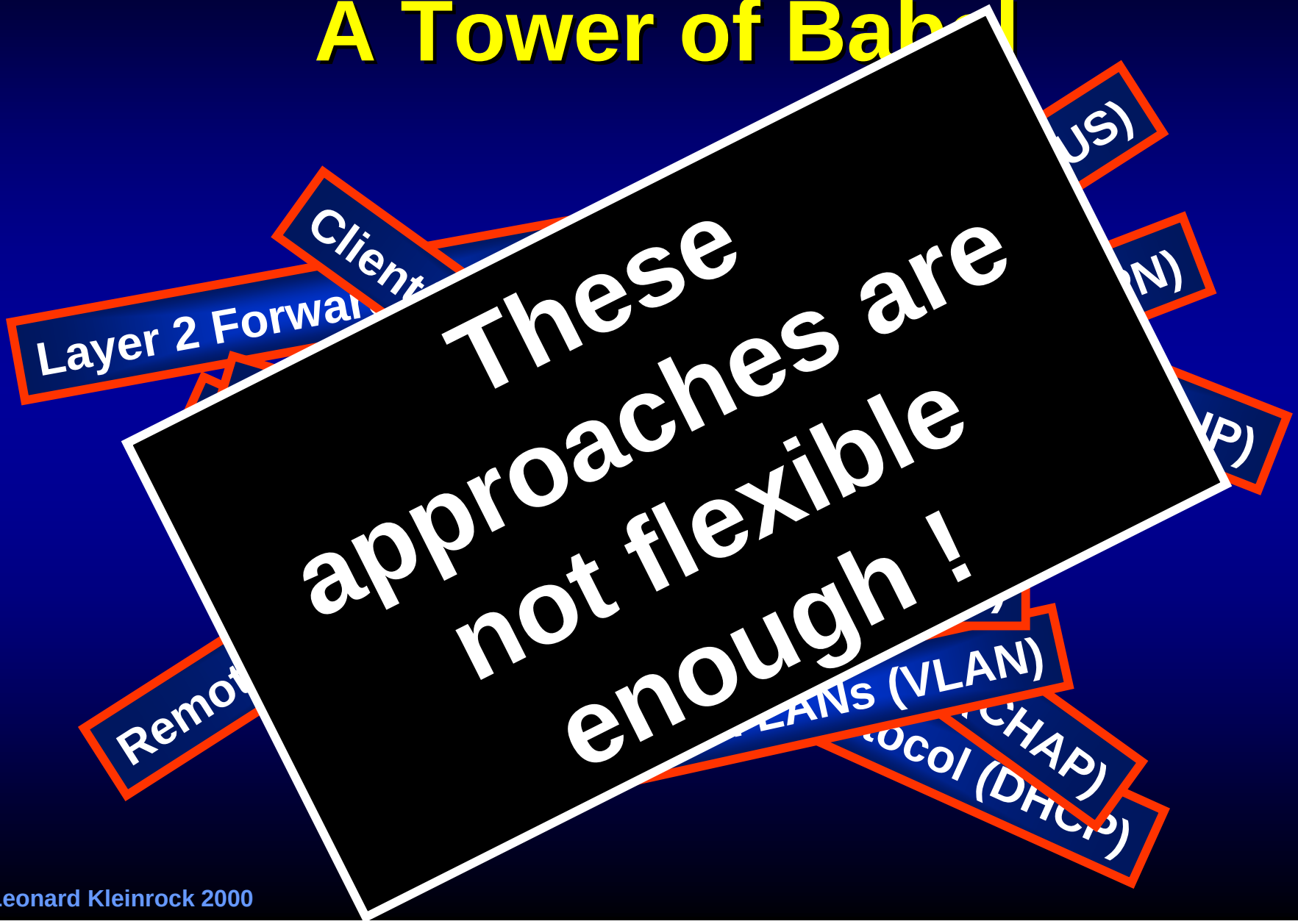
Value Gained Over Multiple Updates



We Need Transparent Adaptation To:

- Context
- Location
- Communication device/bandwidth
- Computing platform
- Application
- Disconnectedness/deferred operation
- Motion

Today's Approach: A Tower of Babel

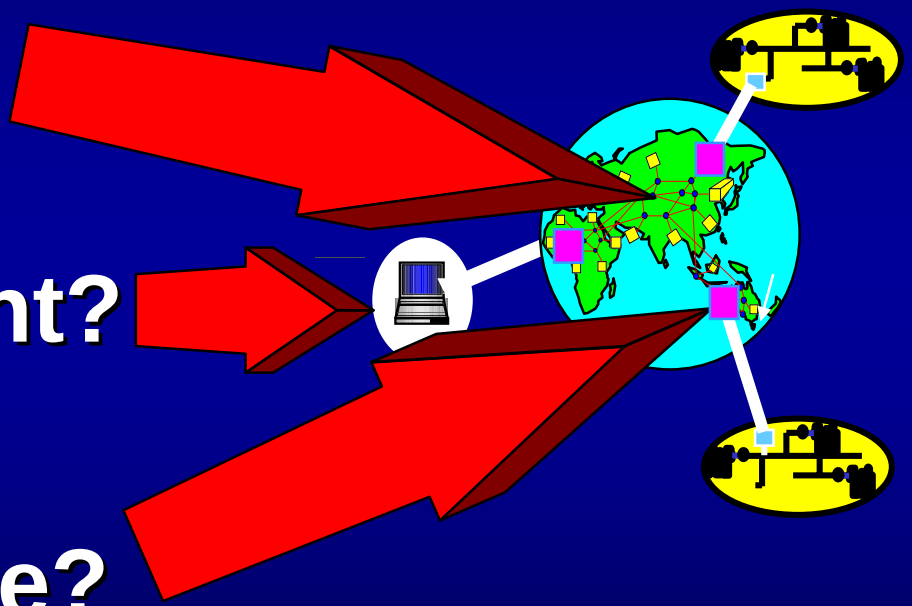


For a More Flexible Approach

1. We need basic management of the subscriber
   - Plug-and-play access to the net
   - Subscriber access to services
   - Reduced setup and administration costs for the service provider
2. We must add intelligence to the network

Where in the Net Should This Intelligence Go?

- In the core?
- In the client?
- At the edge?



This Intelligence Should …

1. Not be deep in the core since we want fine customization and control of individual users (or small groups)
2. Not be in the client since they are getting skinnier:
3. Be deployed at the next closest plac in the net, namely … at the edge.

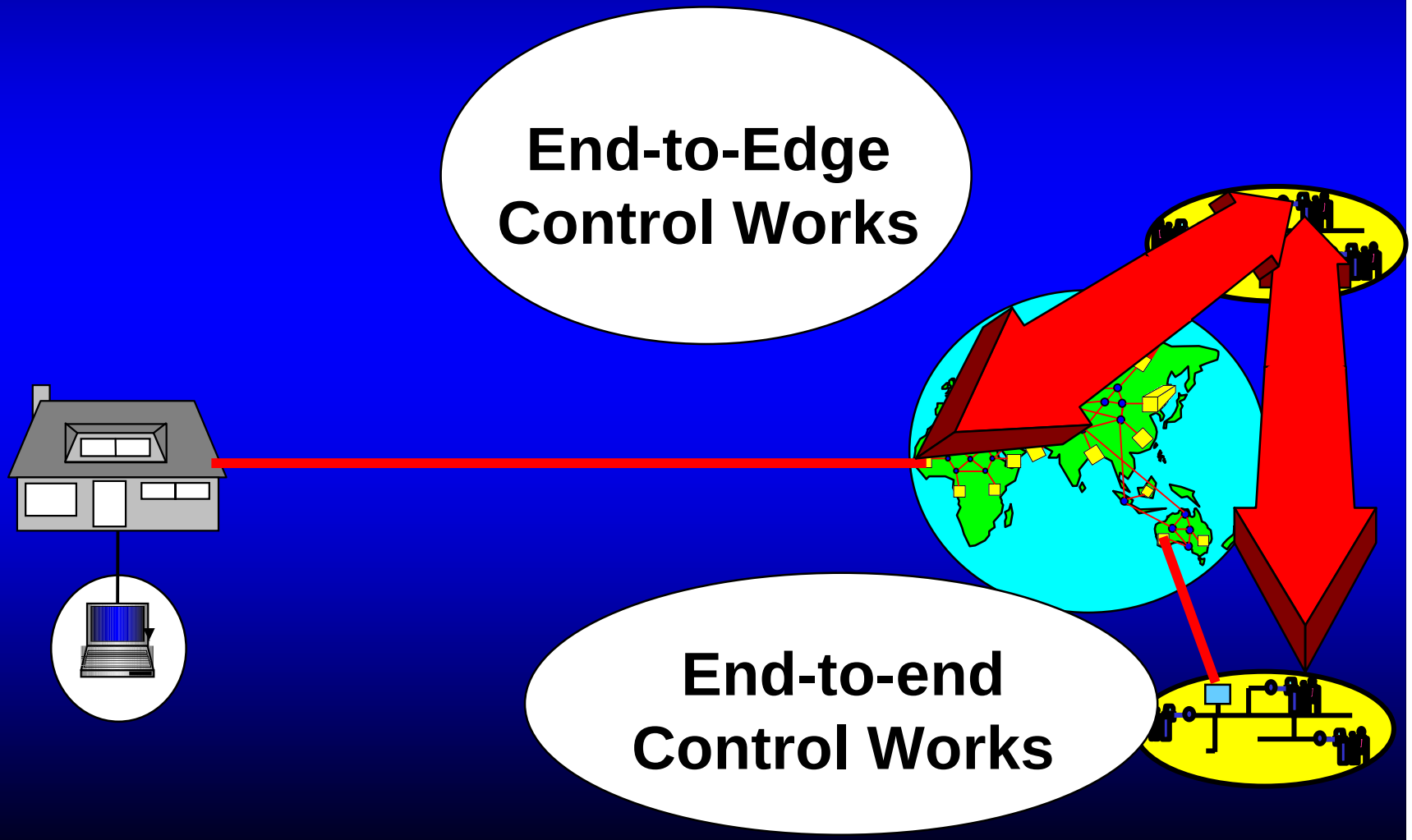
What's So Great About the Edge?

Or

Why Should The Intelligence Go There?

- Traffic management at the edge is becoming a key method to increase "bandwidth" and lower costs
- It is the only point in the network through which all subscriber traffic and content flows.
- The Broadband Subscriber Edge is
  - Where the Last Mile Meets the Backbone,
  - Where Access Providers Meet Service Providers
  - Where End Users Meet Broadband Content.
- It is the first place where the End User technology meets the managed infrastructure.

What Can You Control ?



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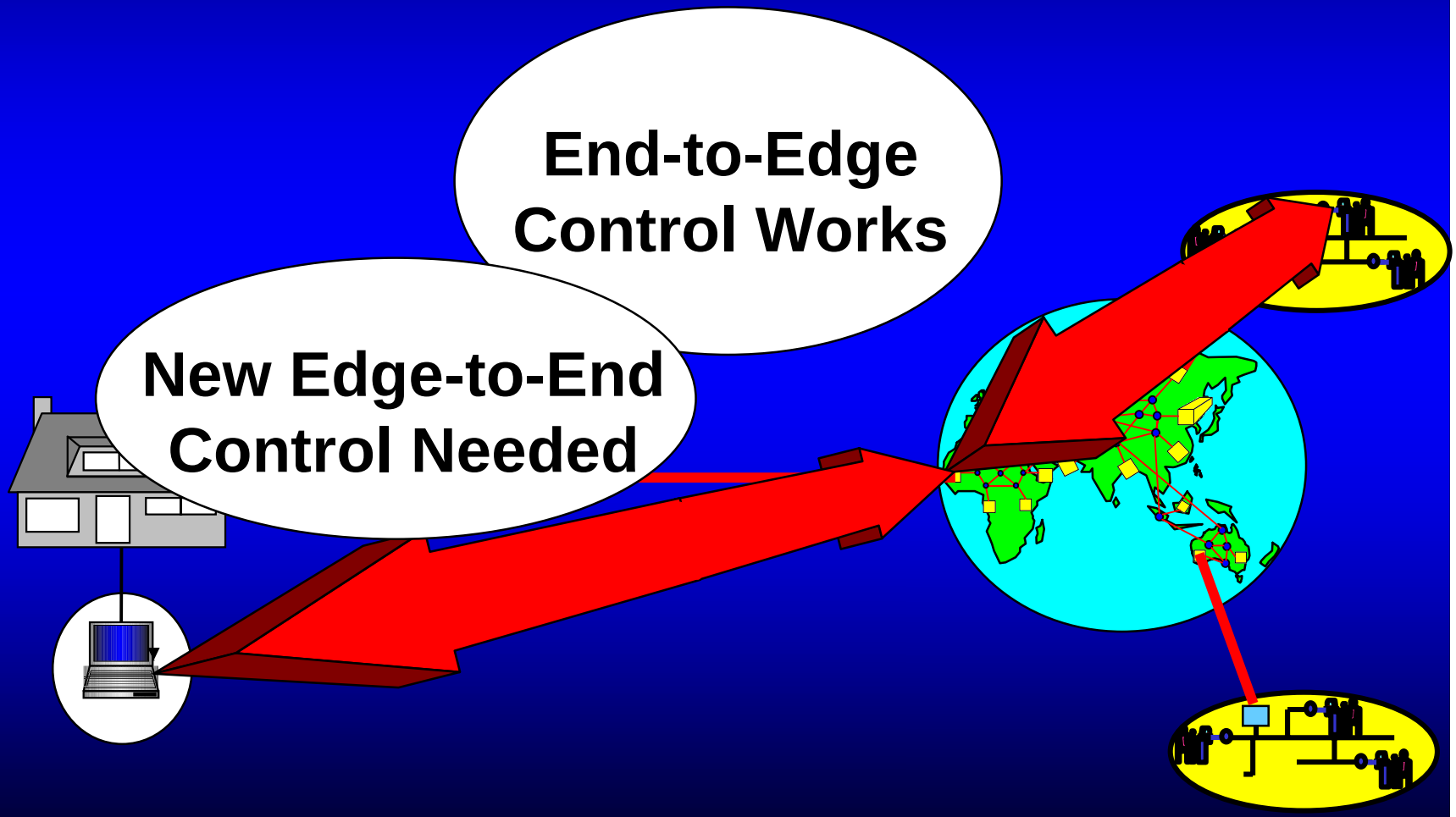


The Internet is Changing

- The Internet is becoming much more than connected networks and computers – it is becoming a service access and delivery system
- ASP's, e-commerce, entertainment, & others will drive this trend

A Change in Thinking

- It is not the "fat pipe" that matters
  – its what goes through it that matters
- The current thinking of
  " 1 pipe = 1 computer = 1 user" model
  will need to evolve to match actual use

From Connections to Service !

Connection Centric

- TCP/IP allows access to local net and Internet
- Local services include printing and e-mail
- Typically connected to LAN with high bandwidth
- Expect to connect to a single network
- Assumes you access the net for a computer app. or service

Service Centric

- Connection predicated on ability to pay
- Local services include pizza and movie tickets
- Typically connected to WAN with low bandwidth
- Select services from multiple networks
- Assumes you access the net for commercial or consumer service

Phase 3:

Smart Spaces

We must move

From

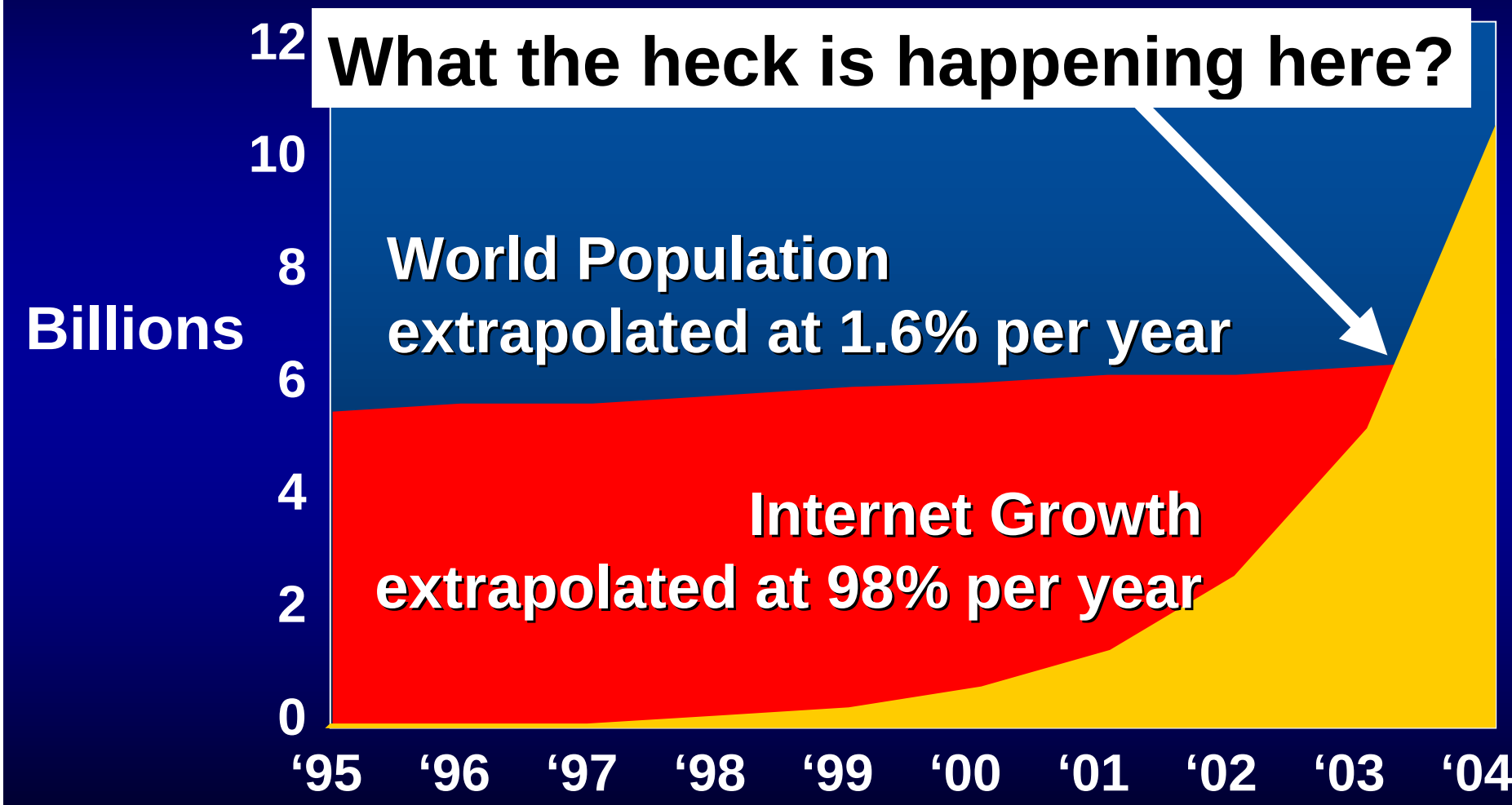
The Netherworld of Cyberspace

To

The Physical world of Smart Spaces

(or the Post-PC World)

Internet growth



So What WILL be Connected?

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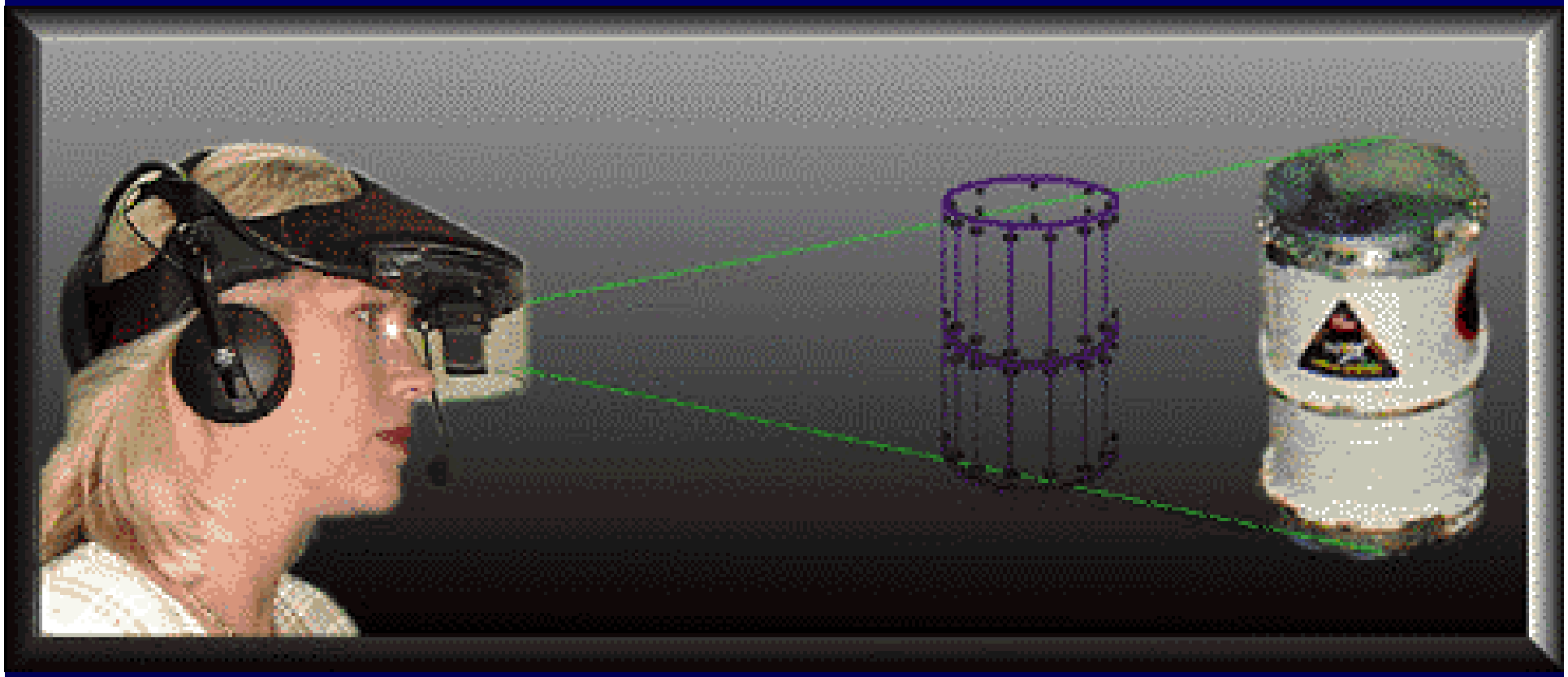

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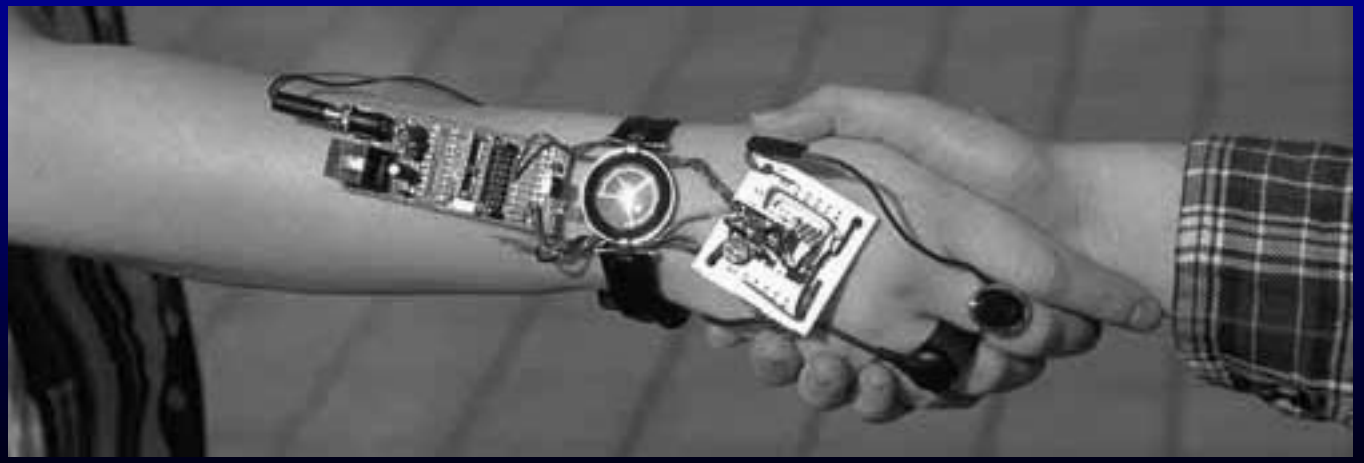


So What WILL be Connected?

So What WILL be Connected?

What Will it Look Like?

- Our environment will be alive with technology all around us
  - In the walls
  - In my desk
  - In my belt
  - In my eyeglasses
  - In my refrigerator
  - In my automobile
  - In my fingernails

Smart Spaces and Smart Networks

- Thousands of processors per human
  - Logic, memory
  - Communications
  - Actuators, sensors
  - Cameras,
  - Microphones, speakers
  - Displays
- Pervasive Embedded Technology
  - Body Net
  - Objects
  - Vehicles

Capabilities Associated with Devices in Smart Spaces

- **Sense**
  - Discover what is in the environment
- **Actuate (control)**
  - Control the elements in the environment
  - Achieve goals in the environment
- **Locate**
  - Find objects, people, information
- **Navigate**
  - Find paths to objects, locations, people and information

Capabilities Associated with Devices in Smart Spaces

- **Organize**
  - Gather information, objects, people
  - Organize information, objects, people
  - Manage affairs of people and missions
- **Report**
  - What is the current situation in the environment
- **Communicate**
  - Interact with objects and people via data, voice, video, tactile

Interacting Environments and Smart Networks

- **Smart Static networks**
  - Smart buildings, rooms, aircraft carriers
- **Smart Mobile networks**
  - My bodynet - I walk around with it
  - My automobile
- **These networks dynamically move into each other's "reach" or "sense-radius"**
  - They interact and activate the smart space capabilities
  - They may need to configure themselves before, during and after the interaction

So What's the Vision?

- The Internet technology will be everywhere
- Always accessible
- Always on
- Just like electricity
  - It's everywhere
  - You don't have to think about it

And it will be INVISIBLE!

What is this Really About?

Money?

Impact?

Fun?

Reaching out?

Doing good?

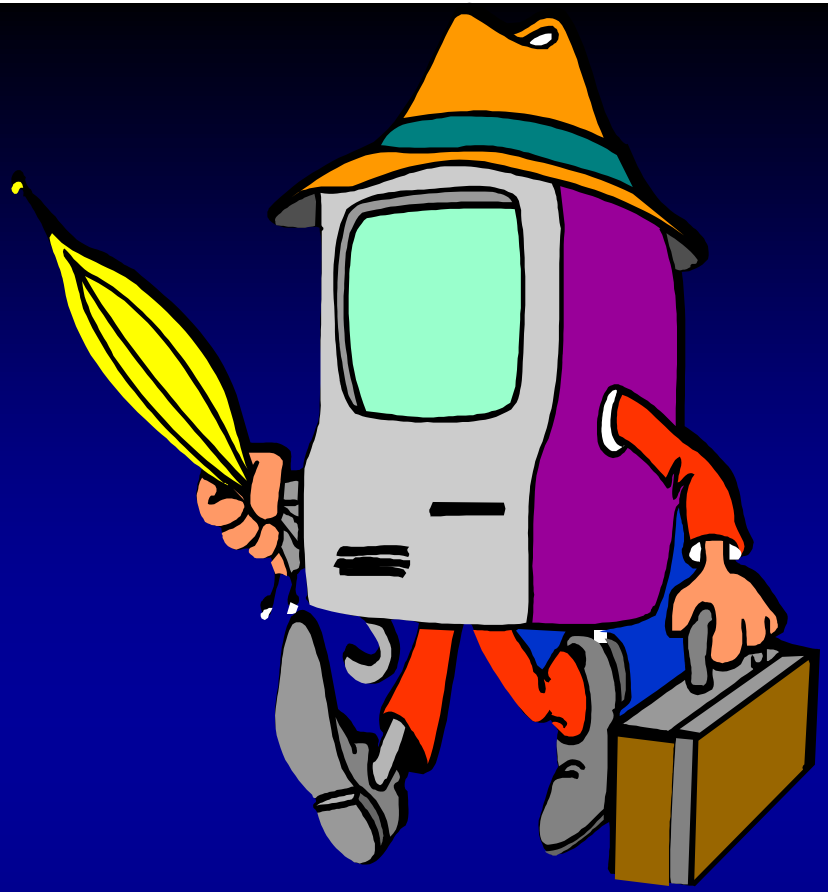
Challenges?

Shopping?

Doing bad?

...

Yes!



Thank You

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