Infosphere:
Smart Delivery of Fresh Information

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with

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DARPA/ITO Expeditions

- MIT's Oxygen project (Sci. Am. 99/08)
- UC Berkeley's Endeavour (Wired 00/01)
- CMU's Aura project
- Washington's Portolano project (with Xerox PARC)
- Georgia Tech & OGI's ***Infosphere*** project

Moore's Law

- Gordon Moore, computer pioneer
  - CPU speed doubles every 18 months
  - Memory density doubles every 18 months
  - Disk storage density doubles every 12 months
- ***Computers almost free***

Network Is The Computer

- Next generation Internet
  - OC12 (622 Mb/s) connections
- Wireless networks
  - Megabit/second wireless connections
- Computer interconnects
  - Gigabit Ethernet, affordable clusters
- ***Networks almost free***

Network Everywhere

- High speed backbone wide area networks
  - Next generation Internet around the world
- Metropolitan and local area networks
  - Wired example: Portland, Oregon
  - Wireless: cellular networks, satellites
- Home and personal networks
  - Bus-based smart homes, Bluetooth

Computers Everywhere

- Traditional computers
  - Mainframes, desktops, notebooks, etc
- Embedded systems
  - Cars, PDAs, cell phones, smart appliances
  - Micro-electronic mechanical (MEM) systems
- Smart environments
  - Sensors, automated controls, monitoring

Ubiquitous Computing

- Plenty of computers
  - Are Everywhere
  - Know Everything
  - Almost Free
- Scarce resource is human
  - User attention span
  - Programmer time

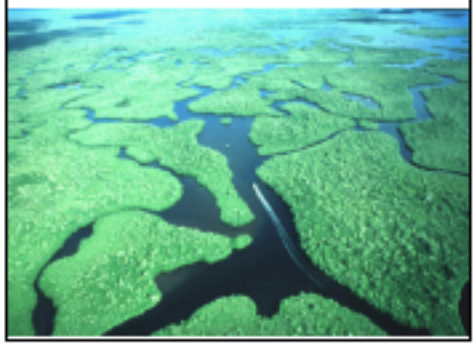
Information Growth

- Storage capacity growth
  - Disk capacity sold per year: Exabytes
- Information content growth
  - All of human published information: Exabytes
  - Computer-generated information: web robots
  - Sensor-generated information

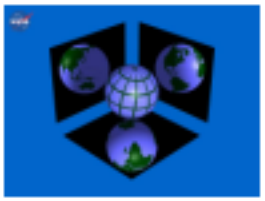
Infosphere Focus Area

- Too many heterogeneous sources
- Too much data
  - Internet data
  - Digital Earth (100TB/day)
  - Smart Dust sensors (thousands p/ km2)

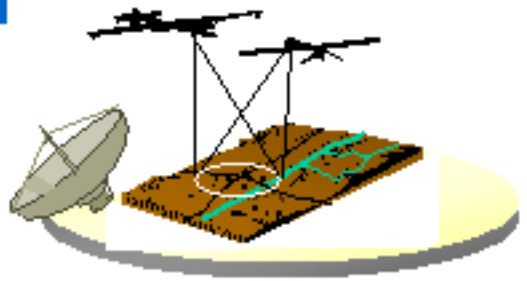
Internet: Information Jungle



Digital Earth



Sensors



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Traditional Computer Science

- **Computational models**
  - Theory: finite state machines, Turing machines
  - Programming languages: programs
  - Operating systems: processes
  - Computer architecture: instruction sets
- **Distributed computations scale poorly**
  - Example: agreement protocols

Information Flow Computing

- Internet applications are primarily ***information flow applications*** (DL, EC)
- Networking success
  - Massive information delivery, QoS
- Historical examples (centralized systems)
  - Dataflow machines in computer architecture
  - Dataflow diagrams in software engineering
  - Unix pipes

Comp. Models & Info Flow

- Focus on algorithms
  - Distributed programs
  - Global algorithms
  - Scalability problems
- Info flow "on the side"
  - Implicit or separate description of I/O
- Localized algorithms
- Global info flow
  - Flow composition
  - Composable properties
- Focus on info flow
  - Explicit description of syntax, semantics, and QoS properties

Infosphere Meta-Approach

- Focus on distributed information flow
  - In contrast to computation-centric computing
  - **Infopipe** as the central abstraction
  - Hypothesis: composable, predictable, scalable distributed software systems
- Missing link: the systems software
  - OS kernel, middleware, data management

Problem: too many sources, too much information

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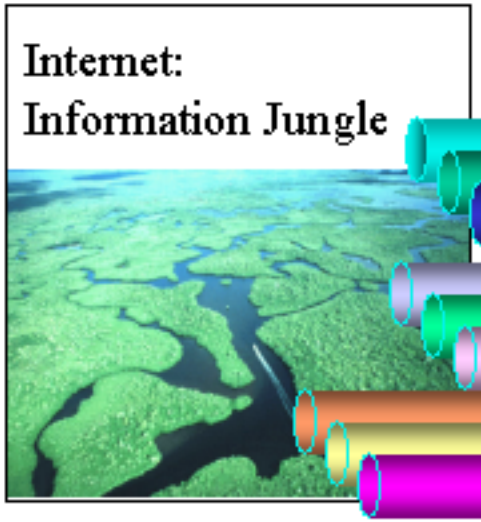
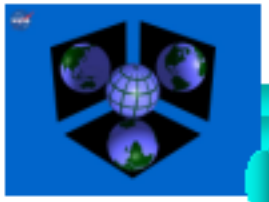
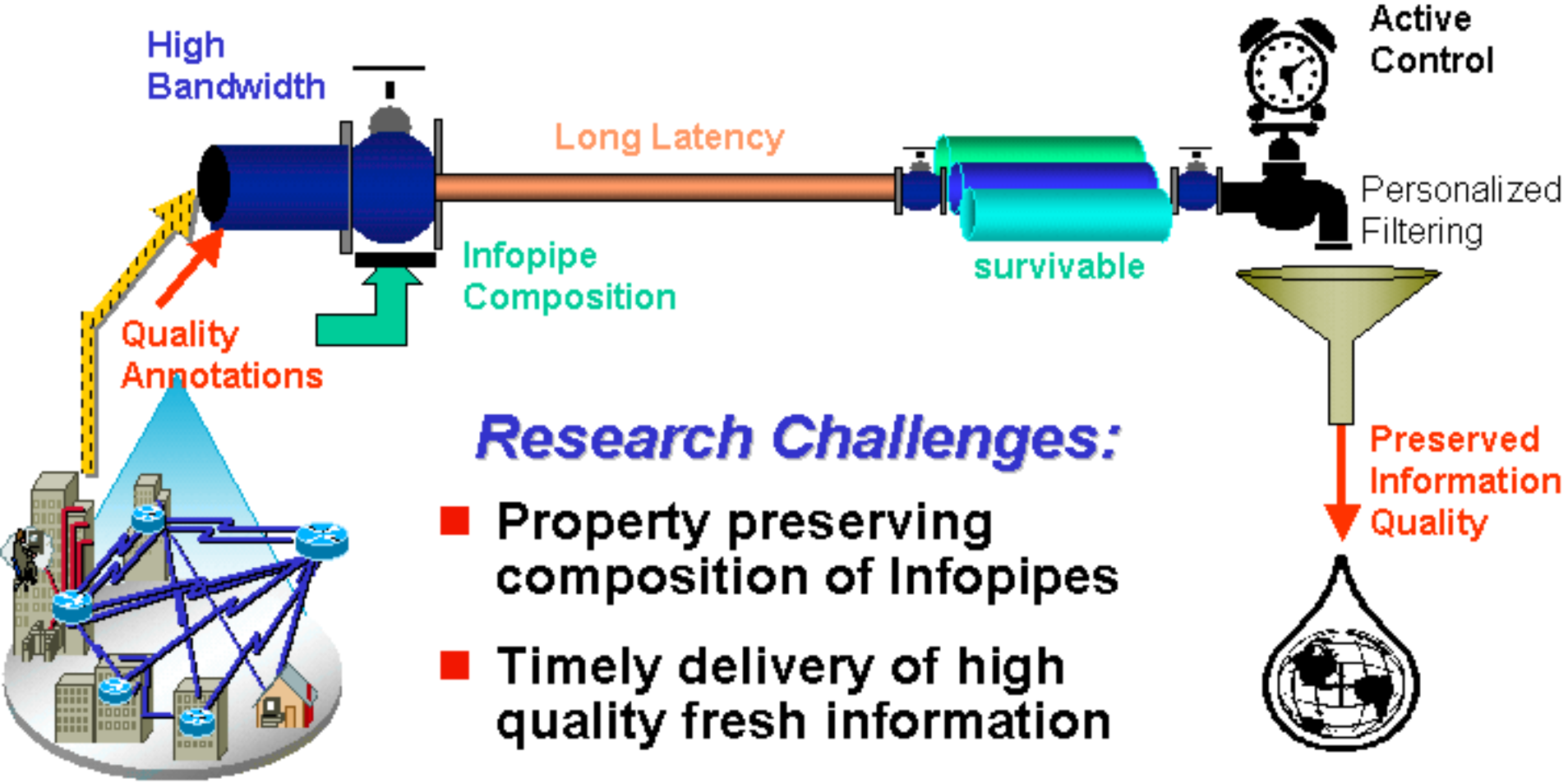




Digital Earth

Sensors

Infopipes: Backbone of Infosphere



Research Challenges:

- Property preserving composition of Infopipes
- Timely delivery of high quality fresh information

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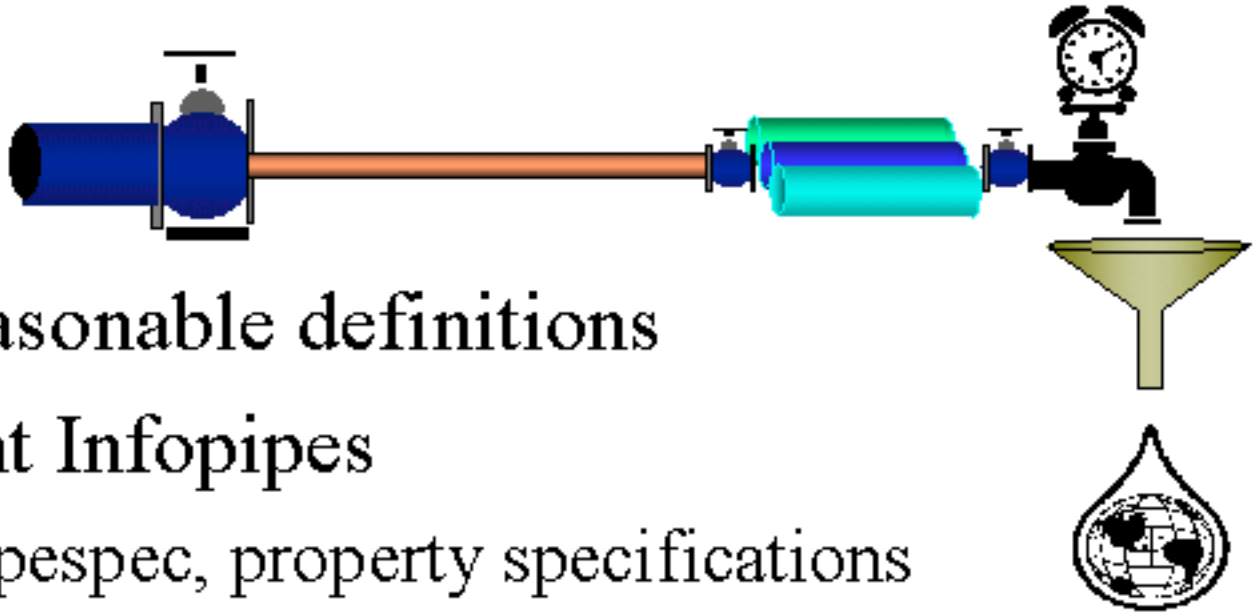
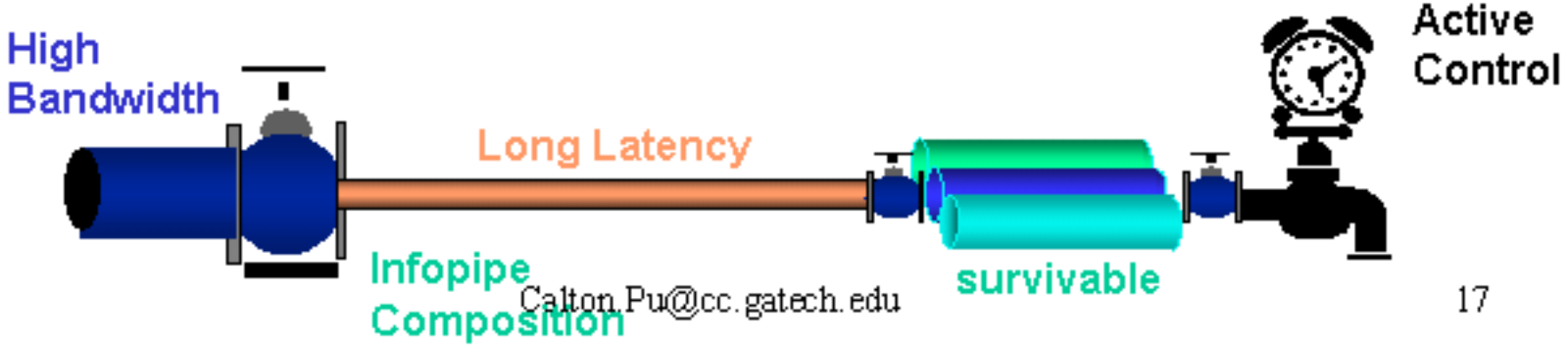
Infopipe Abstraction



- Several reasonable definitions
- Component Infopipes
  - Ends: Typespec, property specifications
  - Middle: processing, buffering, active
- Composition of Infopipes
  - End-to-end property preservation
  - Multiplex ends and middles

Impact on OS Research

- Computation-centric
  - Process abstraction
  - Inter-process communications
  - Synchronization
  - Memory and I/O are "on the side"
- Information-driven
  - Infopipe abstraction
  - Infopipe connection and composition
  - Flow control
  - I/Os are natural flows



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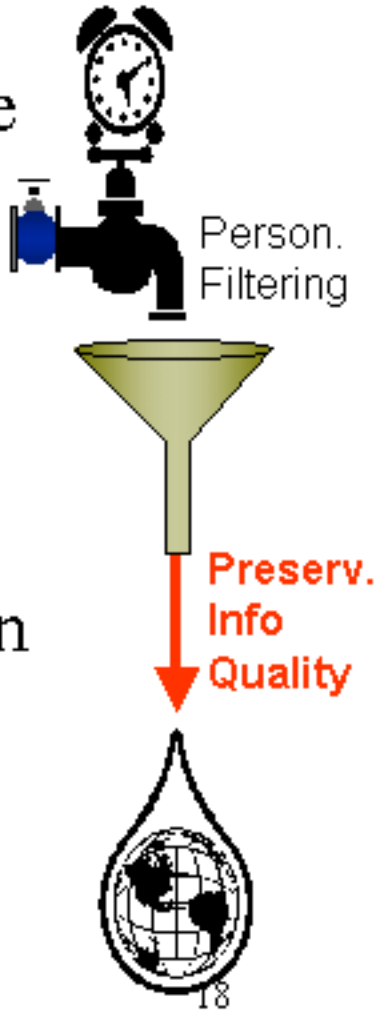
Impact on DB Research

- Traditional DB
- Focus: data reservoir
- Closed world
- Homogeneity and slow evolution
- Static control (DBA)
- Data warehouse

- Infosphere/Infopipe
- Focus: data flow
- Link to real world
- Heterogeneity and rapid changes
- Dynamic adaptation
- Fresh information



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Fresh Information Applications

- Near Term
  - Georgia Tech Aware Home
  - I/O-Intensive embedded systems
- Long term
  - Electronic commerce
  - Personal guidance
  - Environmental observation and forecasting

Georgia Tech Aware Home

- GRA, other funds
- Many sensors
  - 20 video cameras
  - microphones, vibes, …
- Big backend
  - 2 Gigabit connections
  - 128-CPU cluster
- Real-time sensor information laboratory

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Aware Home Projects

- Ubiquitous sensing
  - Recognize people based on their footsteps
  - Multiple camera/multiple person tracking
  - Sensor fault-tolerant scene modeling
- Potential applications
  - Long term elderly care
  - Emergency rescue missions

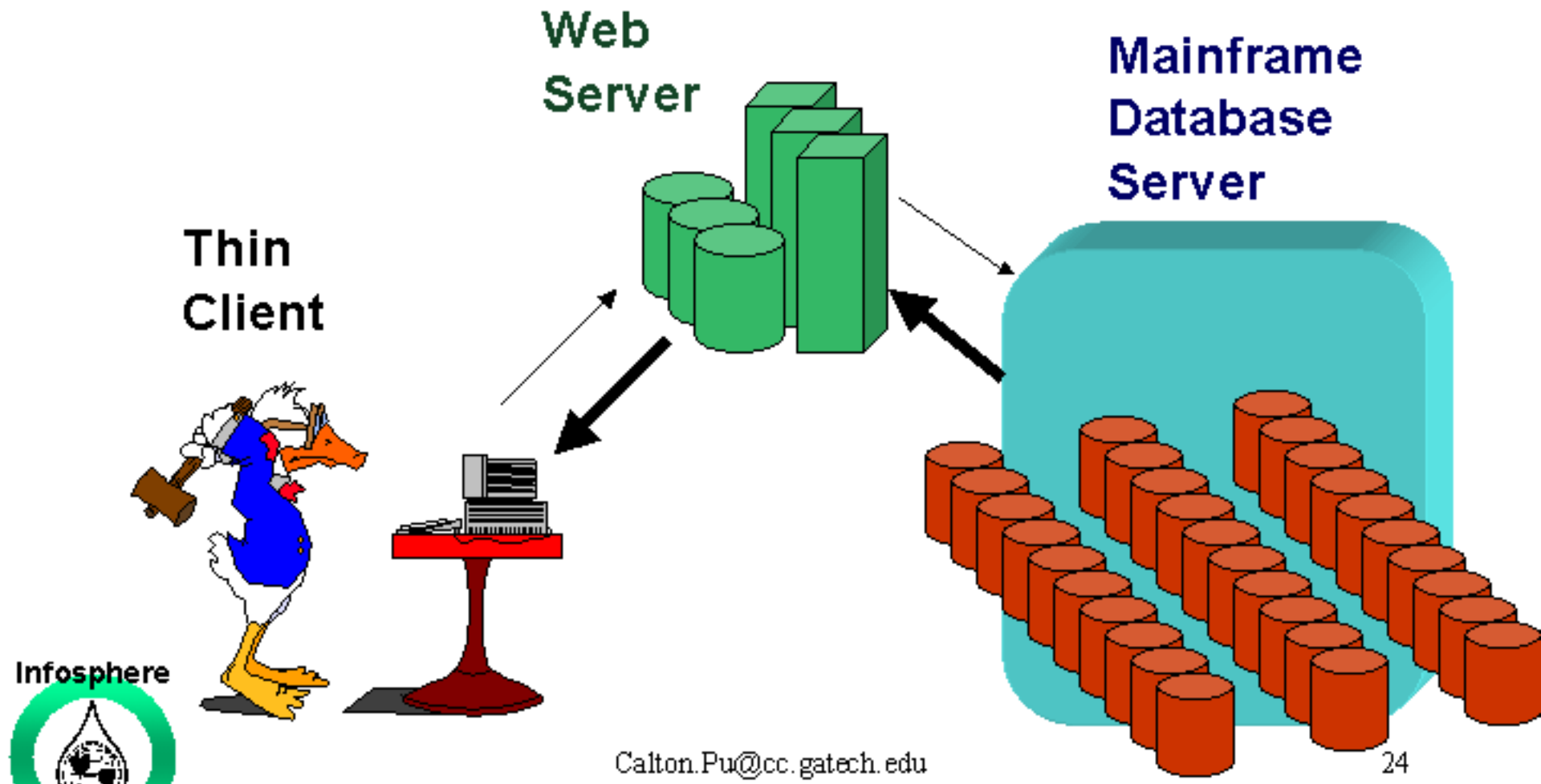
Classic Embedded Systems

- Embedded = Closed
  - Small, independent, self-contained
  - Custom hardware and custom software
  - Small footprint, predictable performance, reliability
- Closed = Limited Evolution
  - Limited hardware and software life expectancy
  - Each generation is a new product

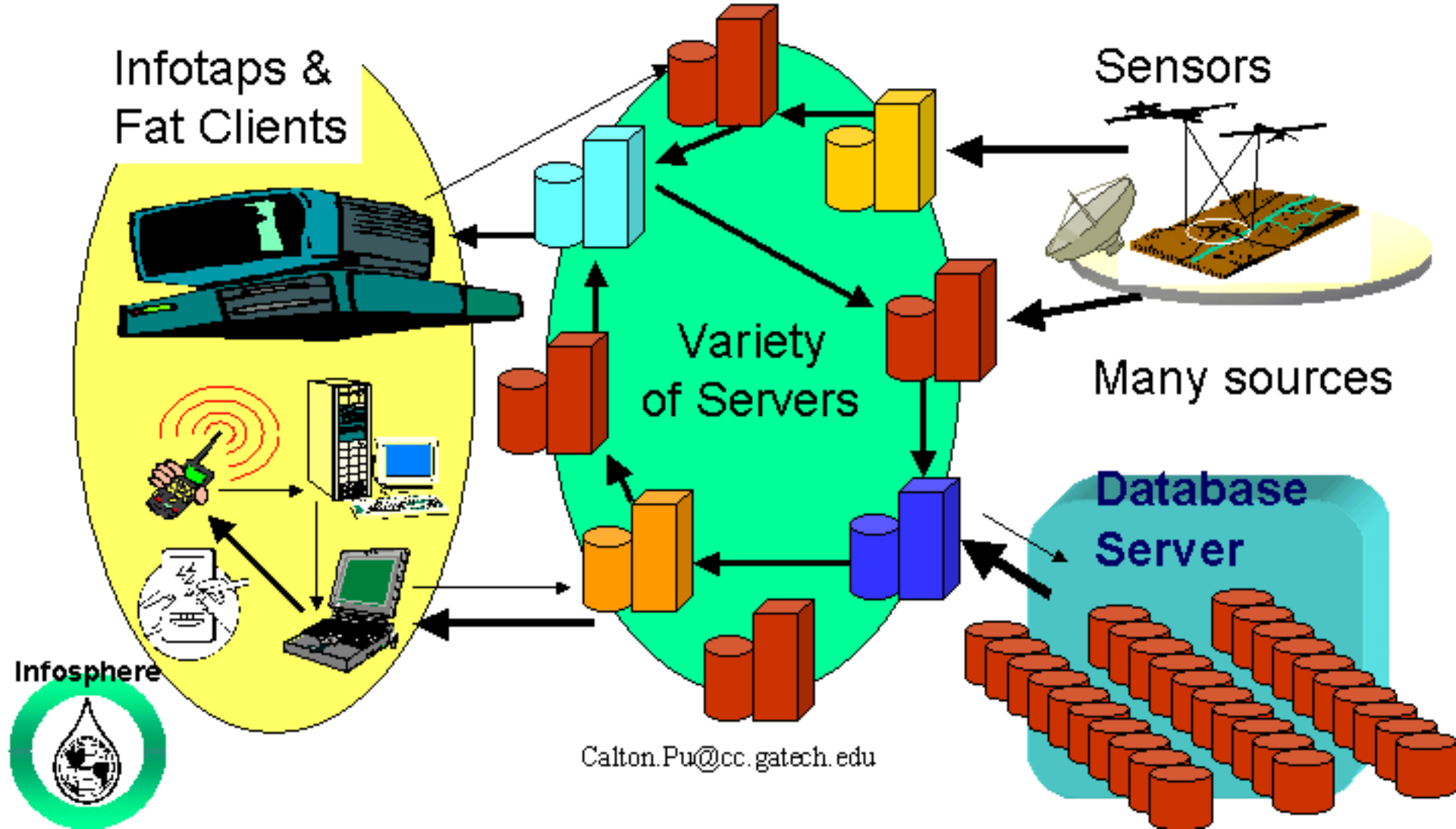
I/O-Intensive Embedded Systems

- **Computers and communications**
  - Sensor-actuators, PDAs, remote control
  - Network is the embedded system
- **Network embedded software requirements**
  - Traditional: small footprint, reliability, predictable performance
  - ***New***: composability, adaptability, extensibility, end-to-end performance

3-Tier Client/Server Today



N-Tier Systems Tomorrow



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E-Commerce Applications

- N-Tier electronic commerce systems
  - Predictable end-to-end latency
- Logistics, real-time decision support
  - Predictable, reliable, real-time information flow
  - Recovery from faults, accidents
  - Adaptation to environmental changes

Personal Guidance Today

- Tele Aid (Mercedes) and OnStar (Cadillac)
  - Cell phone link
  - GPS navigation
  - Human operator
- Palm VII
  - Radio link (cities)
  - Simple web browser

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Personal Guidance Tomorrow

- Traffic-aware road navigation
  - Car receives news, suggests alternative routes
- Cell phones with GPS, WAP
  - Heidelberg tour guide, Digital Kyoto

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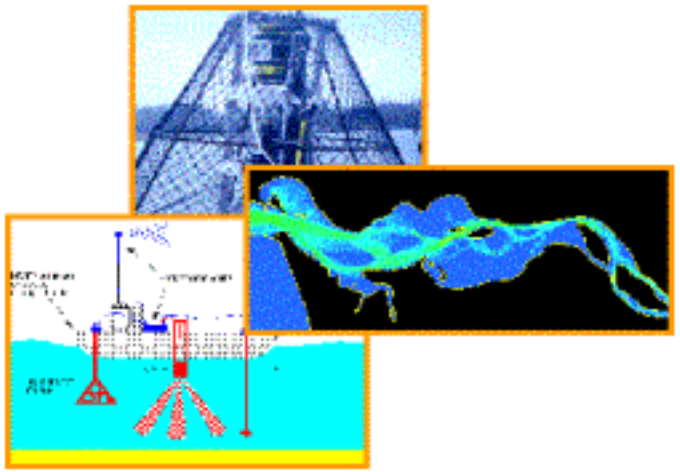
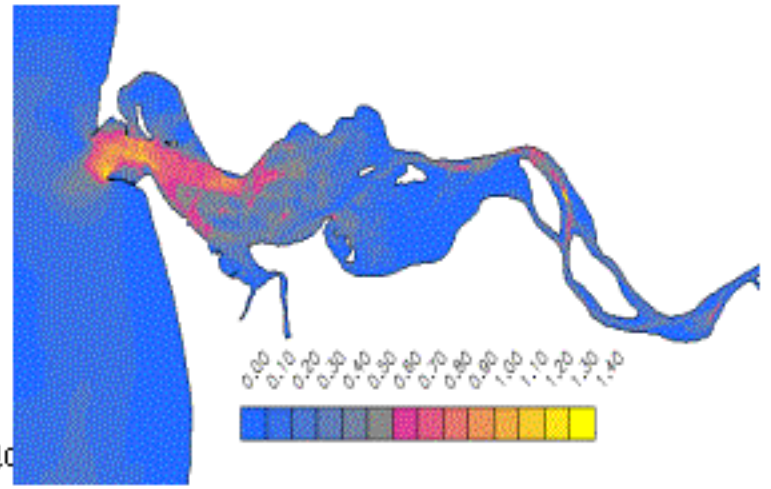
Environ. Observation & Forecast

- Columbia River
  - 2nd in No. America
- Observe (nowcast)
  - 12 data stations in Columbia River Mouth
- Calculate (forecast)
  - Observation-driven model of unpredictable environments





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Tomorrow's Precise Forecasts

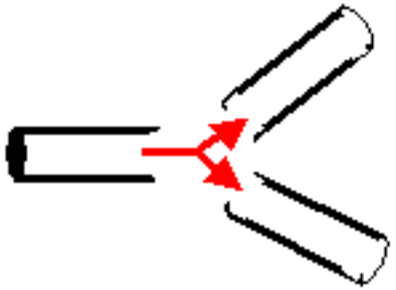
- Many sensors everywhere
  - Video cameras, MEMs, satellites, ...
- Weather-adaptive applications
  - Safe river and shallow water navigation
  - Disaster prevention in precision farming
  - Airline crew and airplane optimization
- Monitoring of environment
  - Amazon illegal timber traffic detection

Infosphere: Current State

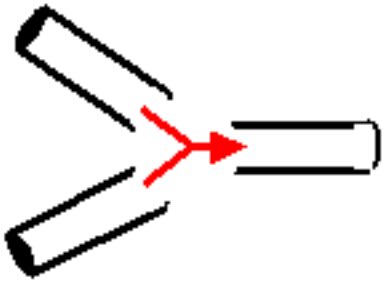
- Infopipe basic research
  - Infopipe concepts and specification (ISL)
  - Infopipe "stub generators" (ISL compiler)
- Infopipe technology development
  - Personalized filtering (Continual Queries)
  - Middleware Infopipes (Event Channels)
  - Kernel QoS Support (Quasar/Microfeedback)

Infopipe Concepts

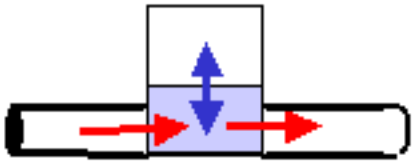
Serial
(1 source, 1 sink)



Multiplex
(n sinks)



Demultiplex
(n sources)



Buffer
(storage)

Filter
(transformation)

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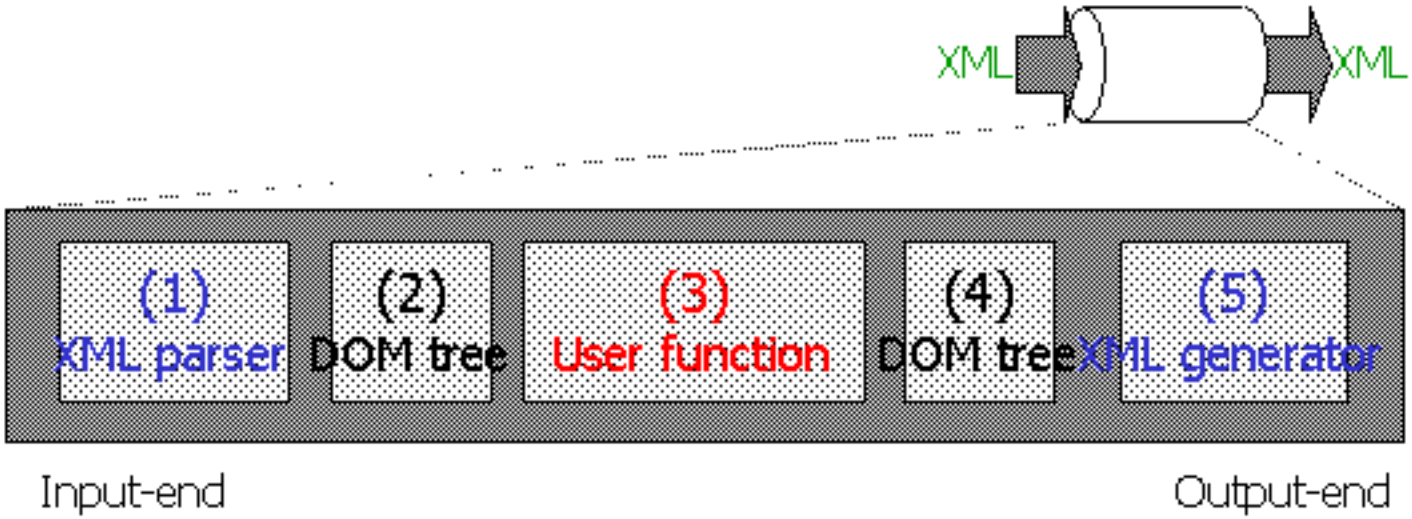
Infopipe Specification

- Syntax of info flow
  - Java class, C record
- Semantics of info flow
  - Currently XML (placeholder)
- QoS requirements of info flow
  - Performance (bandwidth, latency, jitter)
  - Security (level of encryption)

Infopipe "Stub Generators"

- Translate the Infopipe specification into executable code and OS run-time support



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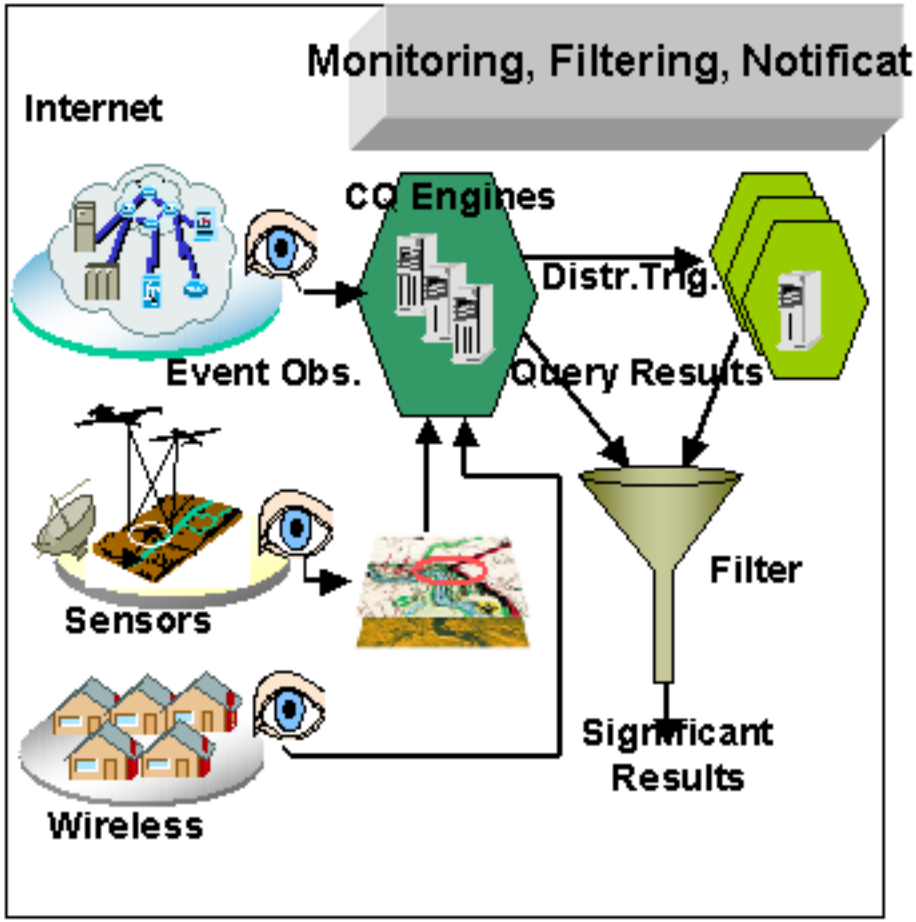
InfoFilters

- Personalized filtering
  - Interesting, important, urgent (IIU)
- Continual Queries
  - Monitoring of IIU updates on the Internet
  - Event-based filtering of new information
  - Pro-active delivery of IIU information



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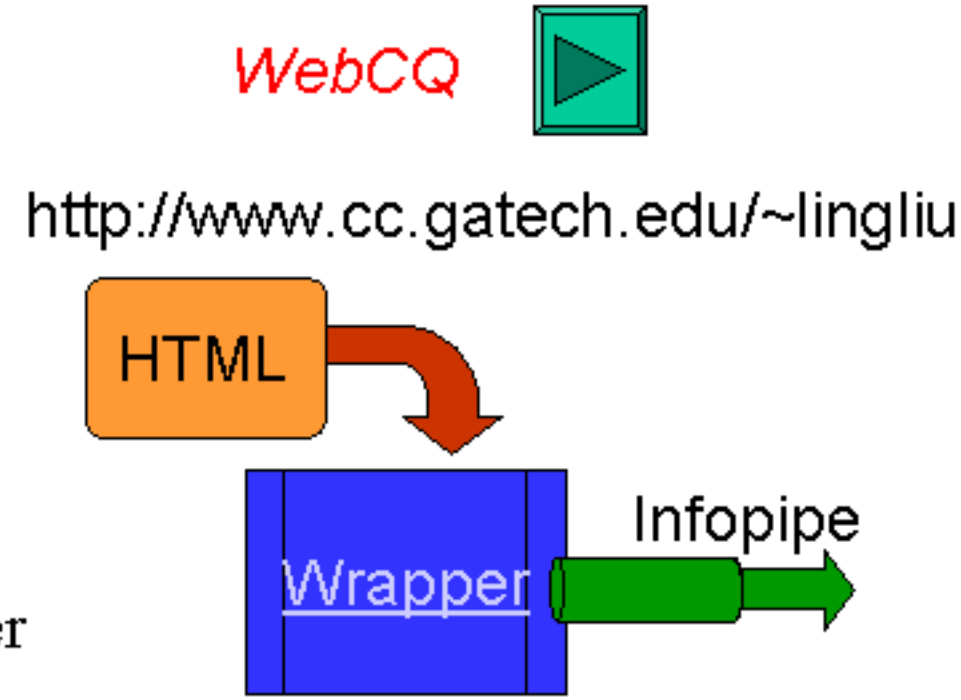
Recent InfoFilter Results

- *WebCQ*: web update monitoring
  - Built on OpenCQ
  - Currently a service
- *XWRAP Elite* Wrapper generator
  - Semi-automated generation of wrapper code



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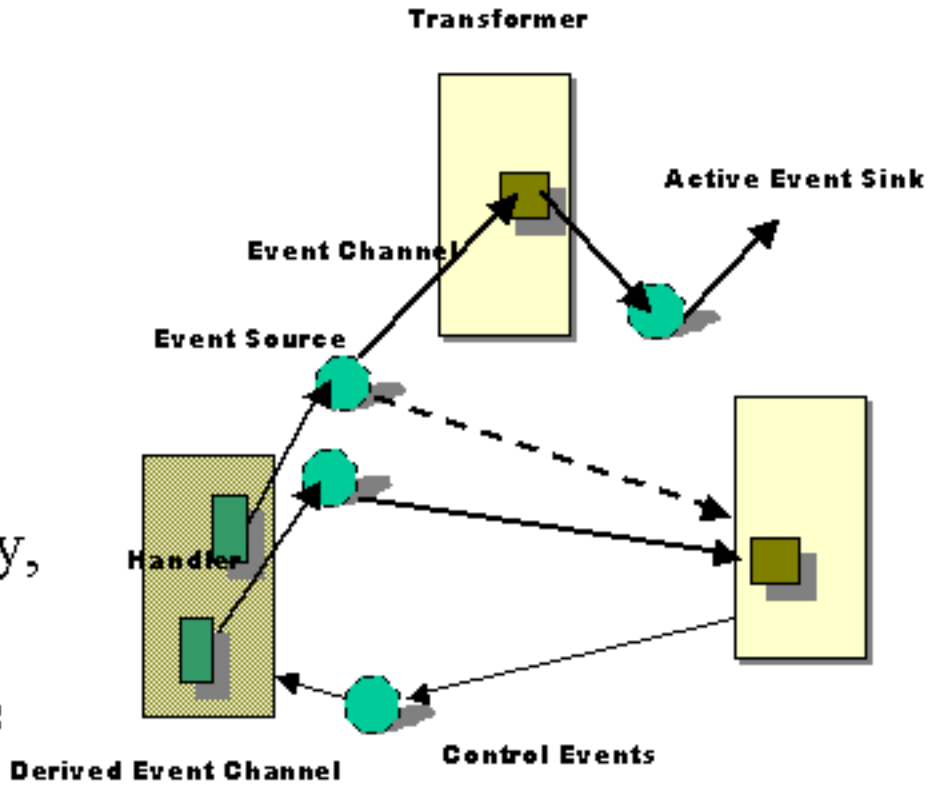
Middleware Infopipes

- Event channels as InfoEvents
  - Publish/subscribe
  - Push/pull
- Quality of Service
  - Performance, security, availability, ...
  - Freshness, timeliness



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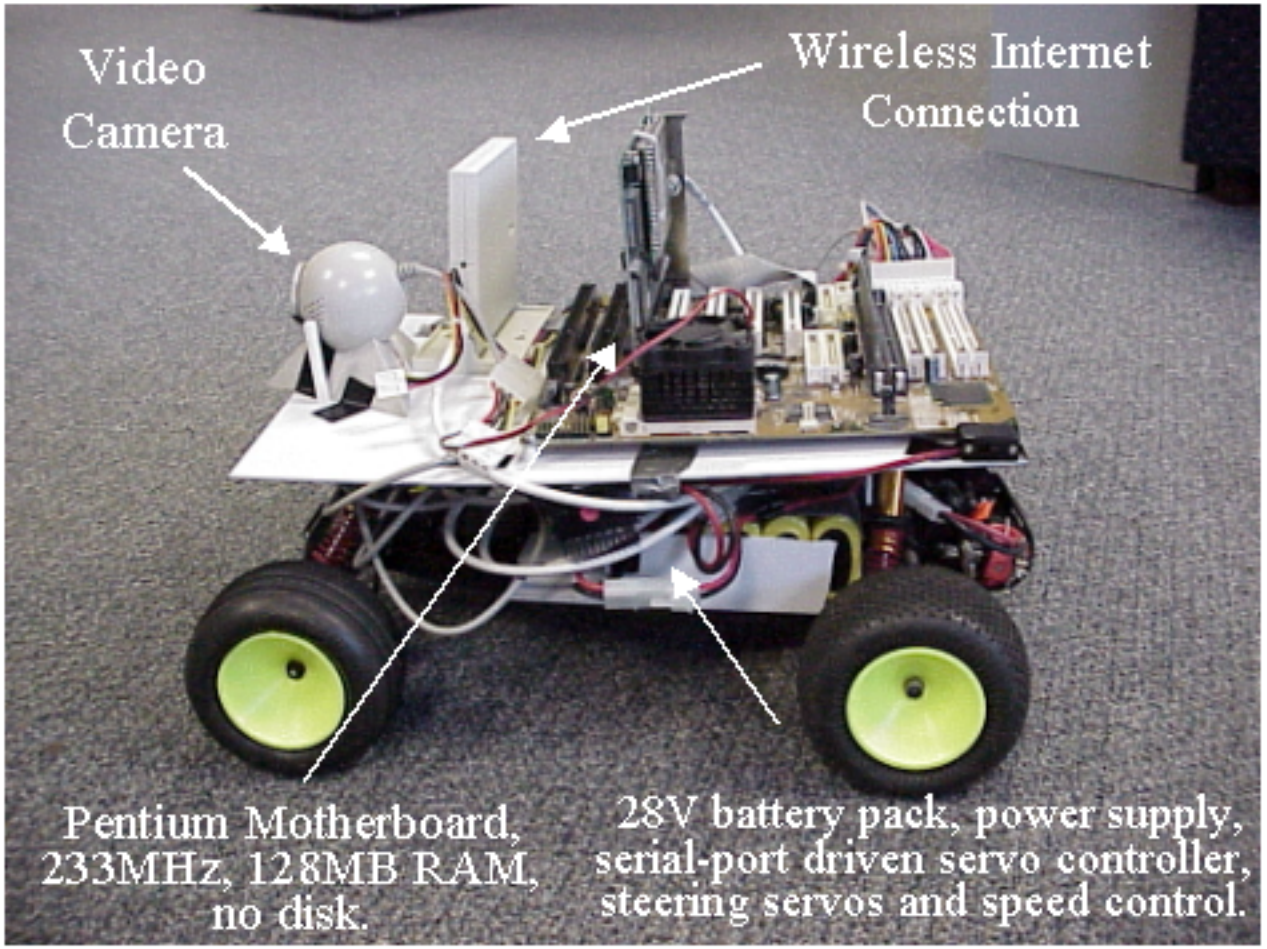
Recent InfoEvent Results

- *DataExchange* software release
  - BPIO: Low-overhead data interchange format
  - ECho: Event Channel code generator
  - JECho: Java Event Channels
  - Heterogeneous distributed platforms
- ***Event channels*** as InfoEvents
  - QoS being added: real-time, security, etc ...

Real-Rate Infopipes

- **Support applications w/ real-world events**
  - Sensor-actuator control and sensor information
  - Routers and active network nodes
  - Multimedia (bandwidth, latency, jitter)
- **Rate-matching and quality degradation**
  - Real-rate OS kernel research
  - Microfeedback-based adaptive mechanisms
  - Utility-based QoS degradation policies

Recent Real-Rate OS Results



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Current Collaborations

- Georgia Tech and OGI
- Specialization of systems software
  - France: INRIA, IRISA, Univ. Bordeaux
  - Japan: Univ. Tokyo, Univ. Tsukuba
- Info flow software, Internet data mgmt
  - Germany: GMD/IPSI
  - Japan: Sony Corp.

Infosphere Summary

- **The ubiquitous computing vision**
  - Many computers everywhere, out of the way
  - Too many sources, too much data
- **Systems software missing link**
  - Information flow perspective
  - Composing Infopipes w/ predictable properties
  - Smart delivery of fresh information

Fresh Information On the World