A “CS Systems View” of the real world
Vision and strategy for tomorrow's challenges
CITRIS/INRIA joint workshop
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University of California, Berkeley
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Where we are... an inward view

FABULOUSLY EXPENSIVE
The cost of new facilities is soaring.

New fab construction costs
$5.0 billion

1965 Actual Data
1975 Projection
Microprocessor
Memory
MOS Logic 1975 Actual Data
Grad Window
You are here!
Where we are... an outward view

 ARPANet

 Internet

 WWW

 2.0 B 1/26/11

 RFC 675 TCP/IP

 1969 1974

 HTTP 0.9

 1.5 B

 1 B

 0.5 B

 United States

 World

 Internet users
 People with access to the Internet. More info »

 Data source: World Bank, World Development Indicators - Last updated December 21, 2010
Confluence across immense scale

Bell’s Law: new computer class per 10 years

Computers Per Person

- $1:10^6$
- $1:10^3$
- $1:1$
- $10^3:1$

years

Mainframe
Mini
Workstation
PC
Laptop
PDA
Cell
Mote!

- 1:10
- 6
System innovation perspective

- Pace and form of innovation driven by emergence of computer classes
  - 70’s shared server
  - 80’s personal, networked, workstation, SMP & MPP
  - 90’s cluster, 00’s internet service, data center
- Hugely effective research community turned inward toward highly competitive conferences
- So far has missed the personal mobile revolution
  - If it looks like a mid-80’s PC “Unix will run on it” and always did
- Industry led the Cloud / Analytics revolution, but research community running fast to catch up
- Just begun to really look at the real world
### A different “Graduation Window”

<table>
<thead>
<tr>
<th>Global temperature change (relative to pre-industrial era)</th>
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<tbody>
<tr>
<td>0°C</td>
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<td>Food</td>
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<td>Water</td>
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<td>Ecosystems</td>
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<td>Weather</td>
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<td>Feedback</td>
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#### Food
- **Today**: Crop yields fall

#### Water
- **Today**: Glaciers melt
- **1°C**: Water shortages
- **2°C**: Rising seas

#### Ecosystems
- **Today**: Reefs damaged
- **2°C**: Species extinction

#### Weather
- **Today**: Storms, droughts, fires, heat waves

#### Feedback
- **Today**: Abrupt climate change

#### Global Temperature and Carbon Dioxide

- **CO2 in parts per million**
- **Global Temperature**
- **1880** to **2000**
Towards an “Aware” Energy Infrastructure

Baseline + Dispatchable Tiers

Oblivious Loads

Non-Dispatchable Sources

Aware Interactive Loads

Communication

LoCal

Generation

Transmission

Distribution

Demand

Communication
Cyber-Physical Systems: A Cooperative Grid

- Availability
- Pricing
- Planning

Monitor, Model, Mitigate
- Deep instrumentation
- Waste elimination
- Efficient Operation
- Shifting, Scheduling, Adaptation

- Forecasting
- Tracking
- Market
Where to Start?

Buildings
- 72% of electrical consumption (US),
- 40-50% of total consumption,
- 42% of GHG footprint
- US commercial building consumption doubled 1980-2000, 1.5x more by 2025 [NREL]

Where Coal is used
Prime target of opportunity for renewable supplies
Our Buildings

Annual Consumption

Environmental \hspace{1cm} Operational

- LSA
- Cory
- McCone
- Soda
- Koshland

Soda Hall Power Consumption: 494 KW

Chart by amCharts.com

Custom period: 2009-01-18 22:00 - 2009-01-24 22:45

Zoom: 1D, 1W, 2W, MAX

CPS 2011 4/12/11
Soda Hall

Annual Consumption

<table>
<thead>
<tr>
<th>kWh/sq ft</th>
<th>LSA</th>
<th>Cory</th>
<th>Stanley</th>
<th>McCone</th>
<th>Soda</th>
<th>Koshland</th>
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National average

Soda Hall Power Consumption: 494 kW

Chart by amCharts.com

Lighting
HVAC
IT and Plug Load
PDUs, CRACs
Servers

Custom period: 2009-01-18 22:00 - 2009-01-24 22:45
Zoom: 1D, 1W, 2W, MAX

CPS 2011
Power-Proportional Buildings?

Stanley Hall: Office + BioScience - 13 NMRs

Min = 72% of Max

Stanley Hall Power (kw) - week

1.45 MW

2.02 MW

Annual Consumption

kwh

kwh/sq ft

National average

Stanley

Cory

McCon

Soda

Koshland

CPS 2011 4/12/11
Power-Proportional Buildings?

LeConte Hall: Office

Min = 31% of Max

Annual Consumption

CPS 2011  4/12/11
Energy Transparent Building

MCL equip

Whole Bldg

DOP HVAC

Central vent

office HVAC

MCL infra

MCL vac

servers

Plug loads

Lighting

Parking Lot

CPS 2011  4/12/11
Intelligence in lo-tech places

Whole Bldg

Energy Data
- Thermostat
- Sensor Data
- Weather Forecast
- Internet

LoCal Server
- Sensor Data
- AC Control

Control Computer
- Sensor Data
- sMAP

Equipment and Occupants
- AC Signal
- Room
- Cool Air

CPS 2011 4/12/11
Learning-Based Model Predictive Control

Experimental Hysteresis Control: 31.7 kWh Consumed

Simulated LBMPC: 19.0 kWh Consumed (estimated)

LBMPC adjusts for internal dynamics, avoids over-cooling, trades off duty cycle and switching frequency

(Aswani, Master, Taneja, Culler, Tomlin, 2011, submitted)
Cyber / Physical Buildings

- Cyber
  - Building Integrated Operating System
  - Activity Models
  - Physical Models
  - BIM
  - Multi-Objective Model-Driven Control
  - Fault, Attack, Anomaly Detect & Management
- Physical Building
  - Human-Building Interface
  - Electrical
  - HVAC
  - Building Management System (BMS)

Control Plan and Schedule
- Activity/Usage Streams
- Pervasive Sensing
- Legacy Instrumentation & Control Interfaces
CPS contributions … ???

- Pervasive Embedded Monitoring Networks
- Power Proportional Design Techniques
- Application Independent Physical Information Representation
- Modeling and Analysis
- Multi-objective Intelligent Control
- Human-Centric Optimization
- Robust, Scalable Infrastructure Architecture
Research as “Time Travel”  
- the secret formula

- **Imagine** a technologically plausible future
- **Create** an approximation of that vision using technology that exists.
- Discover what is **True** in that world
  - Empirical experience
    - Bashing your head, stubbing your toe, reaching epiphany
  - Quantitative measurement and analysis
  - Analytics and Foundations
- Courage to ‘break trail’ and discipline to do the hard science on problems that matter