Data and Information Management in the Built Environment

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Overview

Part 3

Getting Started

Definition of Built Environment

Various Sources (Google, ScienceDirect):

- Human-made surroundings that provide for human activity, ranging in scale from buildings to cities.
- Includes supporting infrastructure: water supply networks; energy networks; transportation systems, communication systems.

Human Needs:

- Basic: Access to clean air and clean water.
- Health: Access to good medical services.
- Economic: Affordable low maintenance housing.
- Security: Protections against crime, environmental attack.

Framing the Opportunity

We seek:

- Data-driven approaches to measurement of performance in the building environment and identification of trends and patterns in behavior.
- Solutions that account for unique physical, economic, social and cultural characteristics of individual cities.

Sources of Complication:

- Multiple domains; multiple types of data and information.
- Network structures that are spatial and interwoven.
- Behaviors that are distributed and concurrent.
- Many interdependencies among coupled urban subsystems.

Framing the Opportunity

Premise of this Class:

- Data mining and machine learning technologies can enhance (not destroy) the built environment.

Basic Questions:

- What are the challenges facing the built environment in the time frame 2020-2060?
- Is present-day technology where it needs to be to make a worthwhile contribution?
- What will the data mining do? What will the machine learning do?
- Are there opportunities for AI, data mining and machine learning to work as a team?

Engineering Sensor Systems

Engineering Sensor Systems

General Opportunities for Sensing

- Enhanced levels of attainable performance ...
- Create new forms of functionality ...
- Improved economics and operational efficency (energy consumption).
- Improved resilience and agility ...

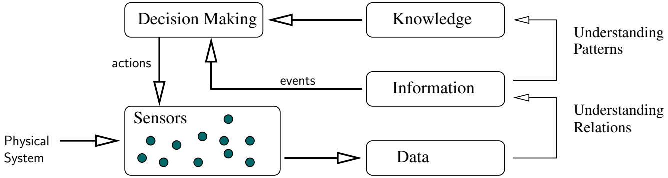
Sensing in the Built Environment

- We need sensors to serve as the eyes and ears of control and information systems designed to make buildings and cities more efficient and environmentally sensitive.

But how will such a system work?

Engineering Sensor Systems

Abstract Model for Sensor System Operations (Simplified!)



Implementation Options

- Human responsible for sensing and control.
- Automation (hardware and software) responsible for sensing and control.
- Human and automation systems cooperate in sensing and control.

Engineering Sensor Systems

Human-in-the-Loop Systems

Pros and Cons of Human Control:

- Human machine comes with five sensor types and reasoning capability builtin!
- Humans have slow response; sub-optimal performance; capabilities degrade with age. Approach isn't scalable.

Engineering Sensor Systems

Instrumented Systems:

Basic premise:

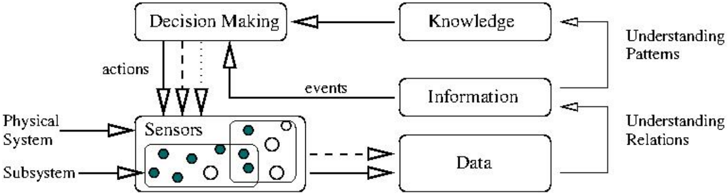
- Advances in computing, sensing, and communications technologies will allow for new types of systems where human involvement is replaced (or partially replaced) by automation.

Examples:

- Autofocus camera,
- Electronic systems in automobiles and planes → self-driving cars.
- Structural health monitoring / building automation systems.

Engineering Sensor Systems

Sensor networks and frameworks for decision making:



Chain of dependency relationships:

```
1.   improved performance <-- actions
2.   actions              <-- ability to identify events.
3.   identify events      <-- data processing
4.   data processing      <-- types and quality of data
5.   types and quality of data <-- sensor design and placement.
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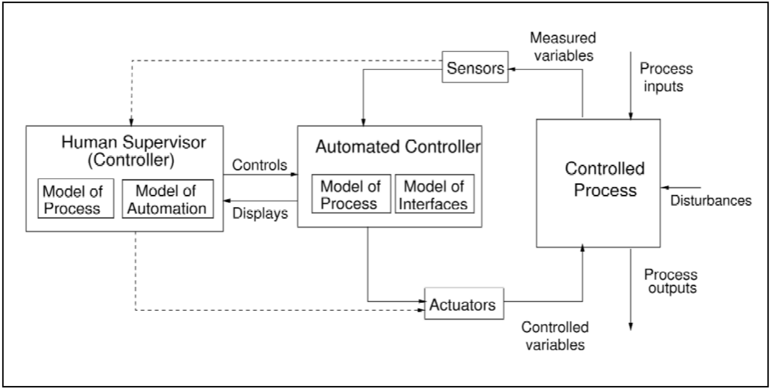
Engineering Sensor Systems

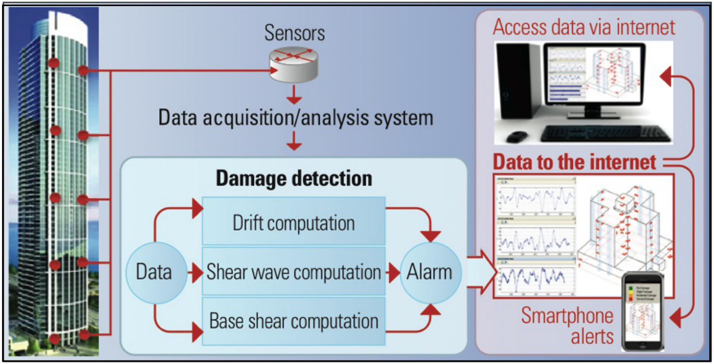
Human-in-the-Loop and Automated Control:



Source: Leveson, 2006.

Real-World Application (Structural Health Monitoring)

Flowchart of activities for real-time monitoring of instrumented buildings.



Source: http://earthquake.usgs.gov/monitoring/buildings/

Real-World Application (Modern Aircraft)

During the past three decades aerospace systems have seen increased use of electrical systems to achieve functionality.

Example 1. Boeing 777 → Boeing 787 (more electric aircraft).

Example 2. F-16 and F-35 Military Jets

F-16

F-35

Real-World Application (Modern Aircraft)

F-16 (production began 1974):

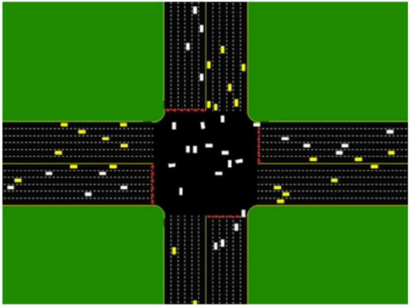
- 15 subsystems; O(10^3) interfaces.
- Less than 40% of the functions managed by software.

F-35 (production began in 2006):

- 3-8 times the operational capabiloity of previous aircraft.
- 130 subsystems; O(10^5) interfaces.
- New sensor systems to support: situational awareness and targeting; sensor integration and data fusion.
- 90% of its functions are managed by software.

Real-World Application (Self-Driving Cars)

Goal. Improve performance by removing bottlenecks → no human driver; no traffic lights.



Remark: 95% of the requirements are for the system software.

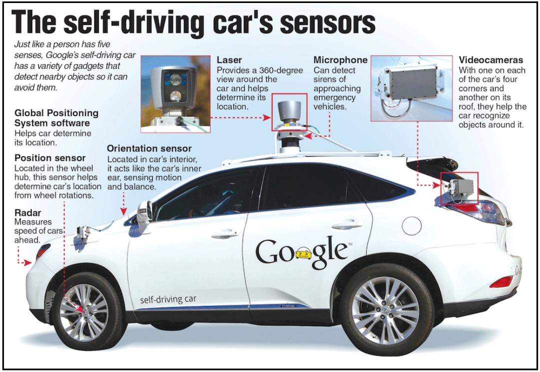
Source: ISR visitor from GM Research.

Remark: Tesla will produce self-driving cars by 2016.

Source: Elon Musk.

Stop signs and traffic lights are replaced by mechanisms for vehicle-to-vehicle communication (Adapted from http:citylab.com).

Real-World Application (Self-Driving Cars)



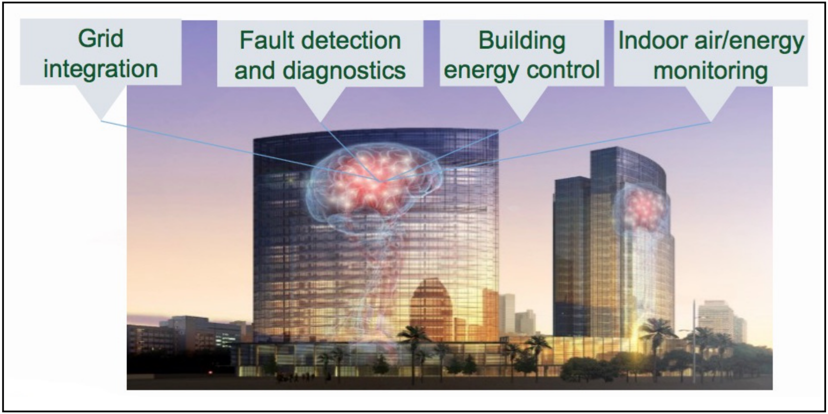
Today: Modern automobiles → 100 million lines of software.
Tomorrow: Self-Driving automobiles → 200-300 million lines of software.

Urban Applications

How do buildings and cities work?

Modern Buildings (Vision for Future)

Buildings that Think! (Work at NIST/UMD 2017)



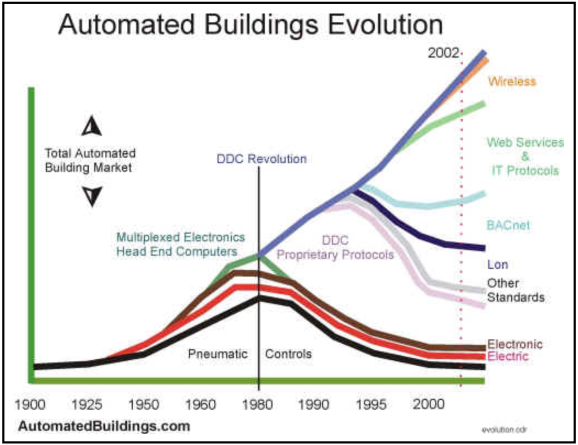
Modern Buildings (Key Features)

Modern buildings are:

- Advanced, self-contained and tightly controlled environments design to provide services (e.g., transportation, lighting, etc).
- Large size (e.g., 30,000 occupants, thousands of points of sensing and control for air quality and fire protection).
- Many stakeholders; highly multi-disciplinary.
- Building have networks for: arrangement of spaces; fixed circulatory systems (power, hvac); dynamic circulatory systems (flows of energy).
- Many sources of heterogeneous data.
- Necessity of performance-based design and real-time management.
- System functionality controlled by software!

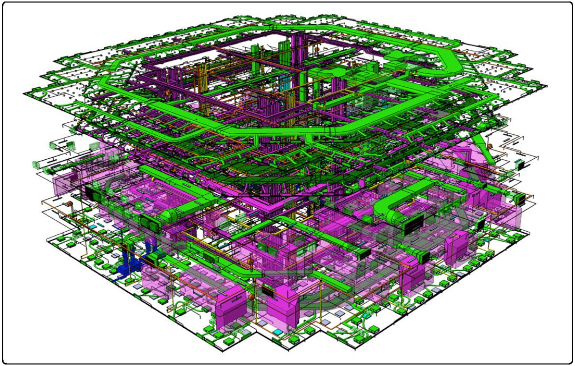
Modern Buildings (Key Features)

Large-scale building systems are packed with automation:



Modern Buildings (Key Features)

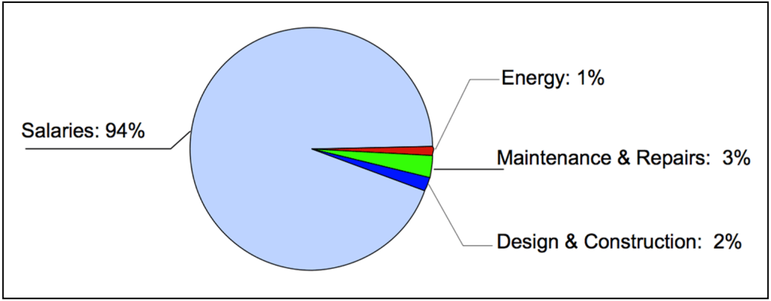
Large-scale building systems are intertwined networks of networks:



Understanding the relationships among the networks and their combined behaviors can be very challenging.

Modern Buildings (Economics)

Lifecycle costs in office buildings over a 30-Year period:



Energy systems have a huge impact on building occupant comfort and indoor air quality which, in turn, affects salary performance.

Source: United Technologies Research Center, 2009.

Modern Buildings (Integrated Energy Systems)

Trend toward Integrated Energy Systems:

- Commercial and residential buildings consume 1/3 of the world's energy.
- And by 2025, buildings will consume more energy than the transportation and industrial sectors combined.
- Standard models of building operation rely on centrally produced power as a source of high-grade energy.
- Advances in technology allow for consideration of alternatives, such as local production of power.

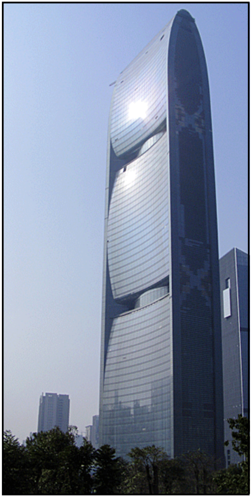
Examples:

- Solar power; small-scale combined heat and power systems.
- Electricity production through use of ducted wind turbines.

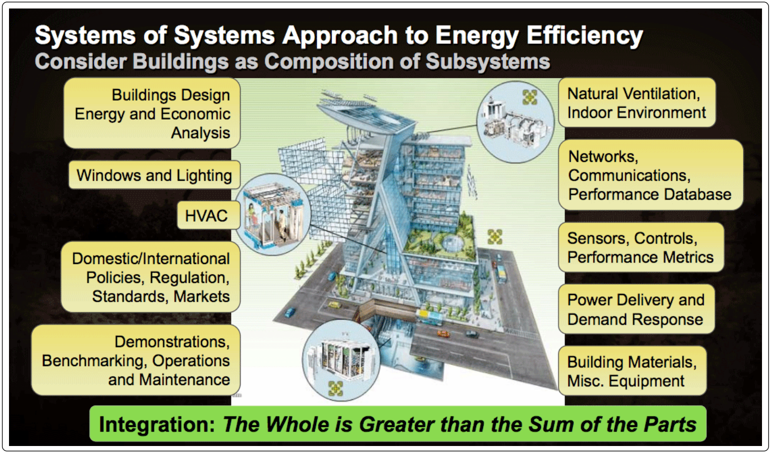
Modern Buildings (Integrated Energy Systems)

Pearl River Tower (2010):

- High performance structure designed to produce as much energy as it consumes.
- Guides wind to a pair of openings at its mechanical floors.
- Wind drives turbines that generate energy for the heating, ventilation and air conditioning systems.
- Openings provide structural relief, by allowing wind to pass through the building.

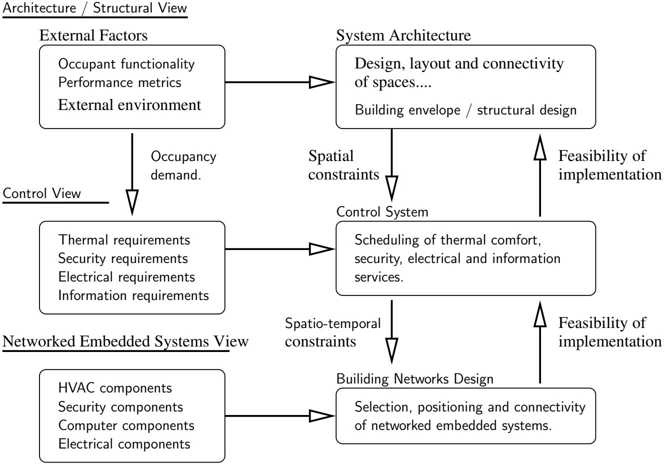


Modern Buildings (Automation Systems Design)



Modern Buildings (Traditional Approach to Design)

Interaction of Muliple-Domains:



Modern Buildings (Platform-Based Design)

Factors Driving Design

Architectural requirements.
Occupancy requirements.
External loads (gravity, thermal, ...)

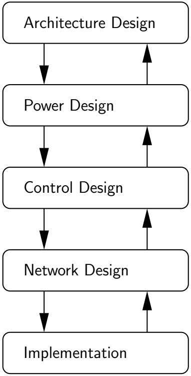
Ventilation requirements.
Energy generation requirements.

Sequence of operations.
Comfort requirements.

Control speed requirements.
Sensor and actuator requirements.

Layout requirements.

Design Flow



Performance

Maximum ventilation.
Maximum power generation.
Cost estimates.

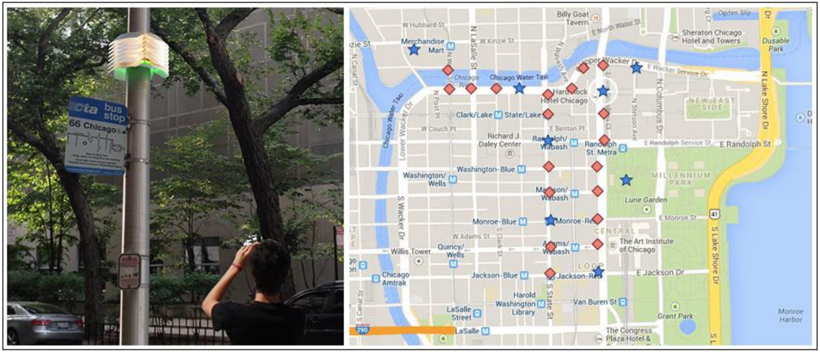
Minimum response time.
Control accuracy.

Maximum available bandwidth.
Maximum computational speed.
Maximum storage size.

Actual ventilation.
Actual power generation.
Actual network speed.
Actual layout constraints.
Actual installation cost.

Smart Cities: Urban Sensing in Chicago

Array of Things, Chicago. Modular sensor boxes will collect real-time data on the city's environment, infrastructure and activity.



Basic Questions. How is the city used? What is going on?

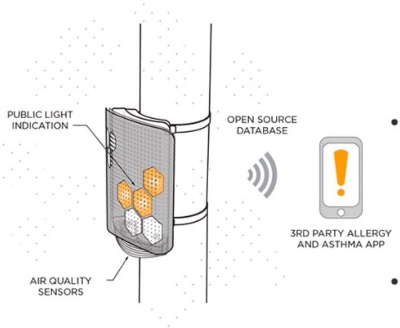
Smart Cities: Urban Sensing in Chicago

What Data is Collected?

The nodes will initially measure temperature, barometric pressure, light, vibration, carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone, ambient sound intensity, pedestrian and vehicle traffic, and surface temperature. Continued research and development will help create sensors to monitor other urban factors of interest such as flooding and standing water, precipitation, wind, and pollutants.

Array of Things is interested in monitoring the city's environment and activity, not individuals. In fact, the technology and policy have been designed to specifically avoid any potential collection of data about individuals, so privacy protection is built into the design of the sensors and into the operating policies. Array of Things will not collect any personal or private information.

Smart Cities: Urban Sensing in Chicago



What Can be Done with this Data?

Potential applications of data collected by the Array of Things include:

- Sensors monitoring air quality, sound and vibration (to detect heavy vehicle traffic), and temperature can be used to suggest the healthiest and unhealthiest walking times and routes through the city, or to study the relationship between diseases and the urban environment.
- Real-time detection of urban flooding can improve city services and infrastructure to prevent property damage and illness.
- Measurements of micro-climate in different areas of the city, so that residents can get up-to-date, high-resolution "block-by-block" weather and climate information.
- Observe which areas of the city are heavily populated by pedestrians at different times of day to suggest safe and efficient routes for walking late at night or for timing traffic lights during peak traffic hours to improve pedestrian safety and reduce congestion-related pollution.

SONYC: Sounds of New York City

SONYC. A system for monitoring, analysis and mitigation of urban noise pollution.

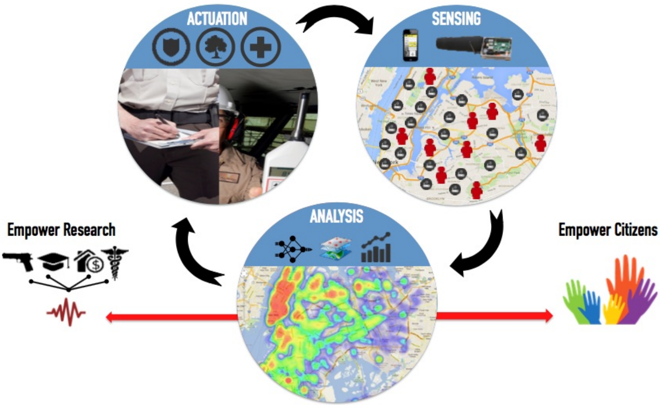
Motivation. Over 70 million people in US are exposed to noise levels beyond the limit of EPA considers to be harmful.

Short-term Problems. Sleep disruption.

Long-term Problems. Hypertension, heart disease, hearing loss.

SONYC: Sounds of New York City

Complaints. NYC authorities receive more than 800 noise-related complaints per day!



SONYC: Sounds of New York City

Noise Analytics. Analyze and understand noise pollution at a city-scale.

Global Applications

Answering Big Science Questions

NASA's Earth Observing System

NASA'S EOSDIS PROGRAM

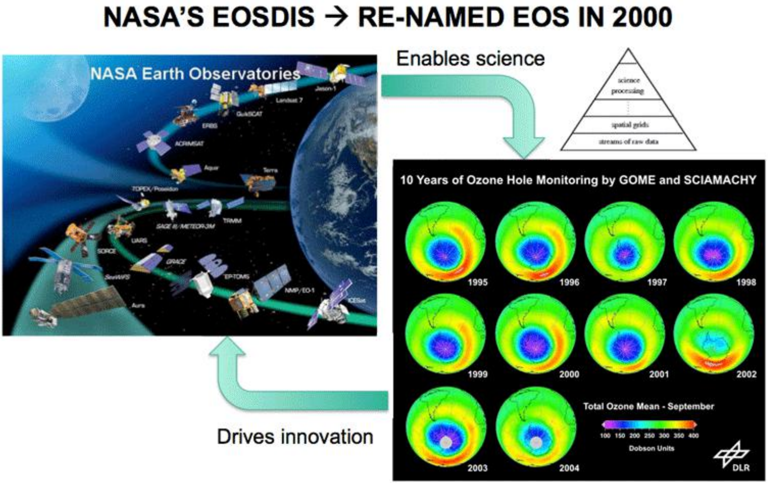
NASA / Hughes Contract in 1993

- Project planning begins in 1989.
- Proposal submitted July 1, 1991.
- Contract awarded 1992.
- $600 million to design and building the infrastructure for a global data and information system that can handle petabytes (2^50 bytes) of data.
- 13 participating countries: USA, Canada, Japan, etc.
- Data collection and information processing: 1995 – 2015.

Big Science Questions:

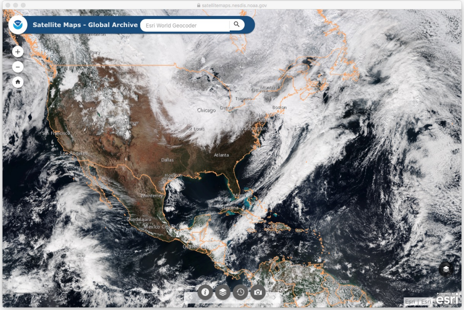
- How is the Global Earth System changing?
- What are the primary factors that influence change?
- How does the Earth System respond to natural and human-induced actions?
- What are the consequences of change in the Earth Systems for humans?
- How will the Earth System change in the future?

NASA's Earth Observing System



Satellite Imagery and Measurements

Understanding Climate Change

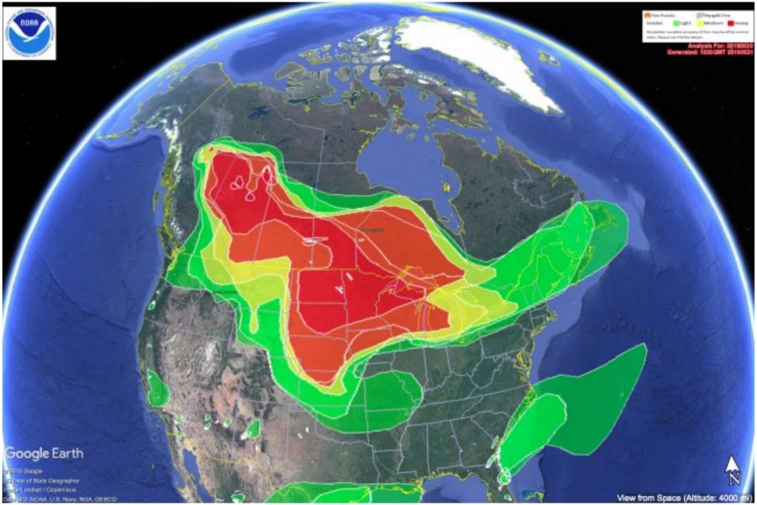


Example. Measure spatial and temporal extent of annual Snow Pack → Estimate water resources available for agriculture and urban consumption.

California Wildfires force Evacuations

Canadian Wildfires impact US

Wildfires in Alberta: Smoke covers millions of square miles:



Canadian Wildfires impact US Health/Food Chain

Poor Air Quality (Summer, 2018):

- Hundreds of wildfires in BC and WA.
- Smoke in BC drifts south to Washington State.
- Air quality in Seattle is very poor.

Wildfires impact Food Chain:

- Blankets of smoke obsure direct sunlight over orchards.
- Apples cannot grow to full size.
- Price of apples at Safeway goes up!

Summary

Recurring Themes and Key Points

Recurring Themes

- Information-age systems offer enhanced functionality and beter performance, but their design is more difficult than in the past.
- Physical systems and computational systems fail in completely different ways.
- Sensor networks will form the eyes and ears of complex control and information systems.
- As system complexity increases, more and more of the functionality will be managed by software!

Key Points for Building Better Systems

Looking Forward

Use sensing and software to build better systems:

- Improve situational awareness – to understand what is actually happending a building or city?
- Connect sensor measurements to short- and long-term urban needs (e.g., decisions on a bus stop; longer term urban planning).
- Capture the spatial, temporal, and intensity aspects of environmental phenomena (e.g., fires, flooding) and their impact on natural (e.g., air quality) and man-made systems (e.g., transportation networks, food chains).
- Look ahead and forecast future states of the system?

References

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