

# Introduction to Civil Information Systems

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# Overview

1 Modern Civil Infrastructure Systems

2 Near-Term Challenges (2020-2060)

3 Infrastructure Protection and Recovery

4 Transition to Information Era

5 Features of Modern Computing

6 Cyber-Physical and Digital Twin Systems

7 Engineering Sensor Systems

8 Urban and Global Applications

Part 5

# Engineering Sensor Systems

# Engineering Sensor Systems

## General Opportunities for Sensing

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

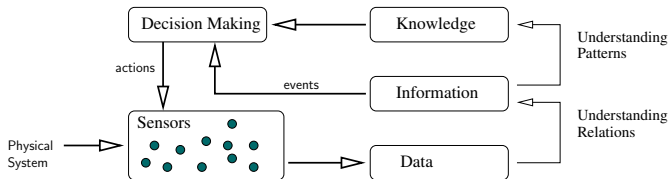
## Sensing in the Built Environment

- 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:

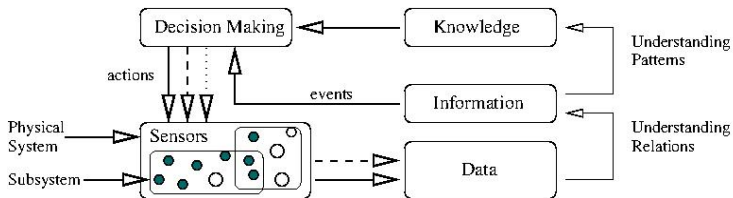
- Advances in **computing, sensing, and communications** technologies will allow for **new types of systems** where **human involvement** is **replaced** (or partially replaced) by **automation**.

## 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:



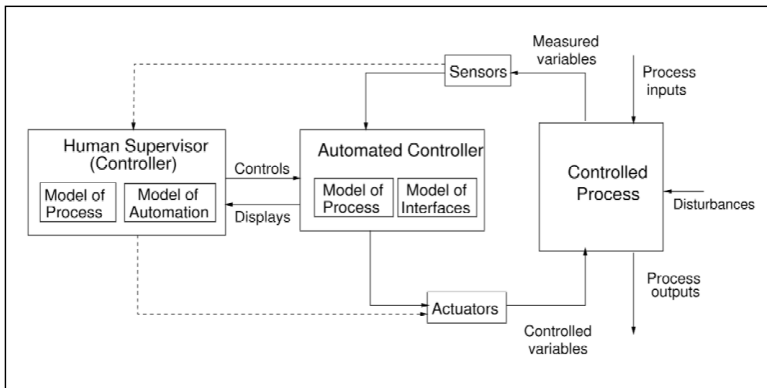
Chain of dependency relationships:

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.



# Engineering Sensor Systems

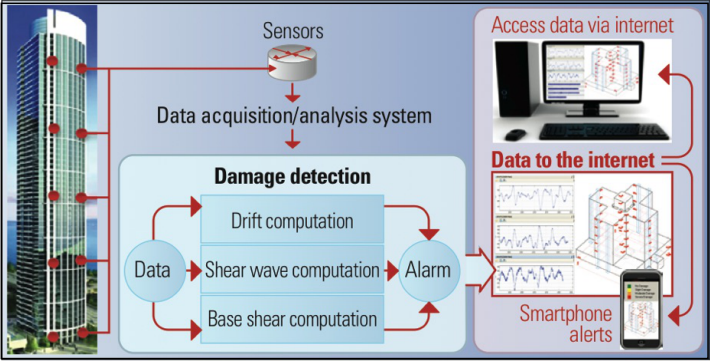
## Human-in-the-Loop and Automated Control:



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):

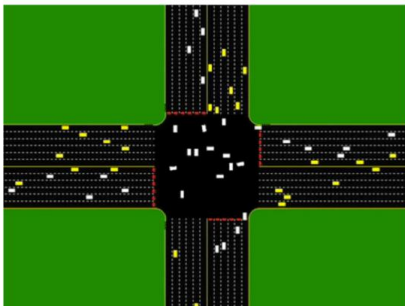
- 15 subsystems;  $O(10^3)$  interfaces.
- Less than 40% of the functions managed by software.

F-35 (production began in 2006):

- 3-8 times the operational capability of previous aircraft.
- New sensor systems to support: situational awareness and targeting; sensor integration and data fusion.
- 130 subsystems;  $O(10^5)$  interfaces.
- 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.

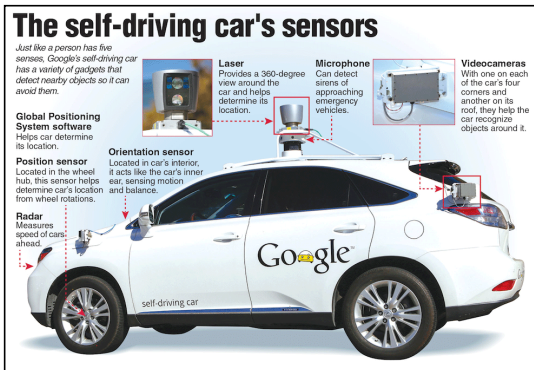
**Source:** ISR visitor from GM Research.

**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.

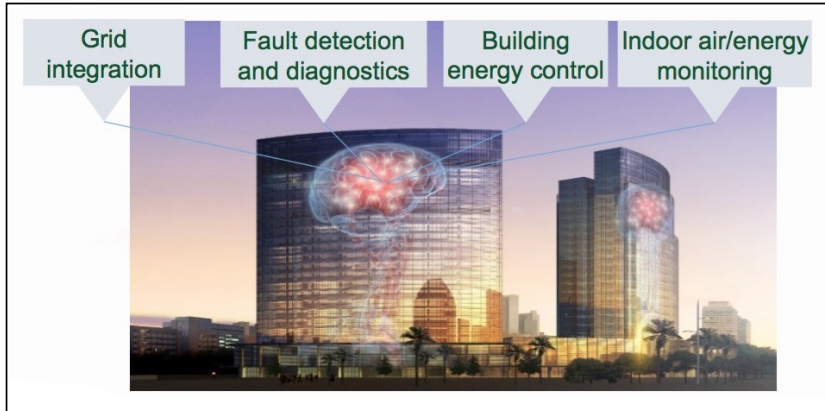
**Tomorrow:** Self-Driving automobiles → 200-300 million lines of software.

# Urban Applications

How do buildings and cities work?

# Modern Buildings (Vision for Future)

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





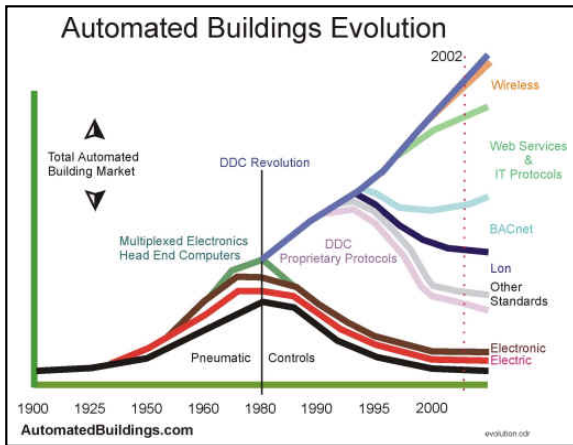
# Modern Buildings (Key Features)

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.
- Buildings 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!

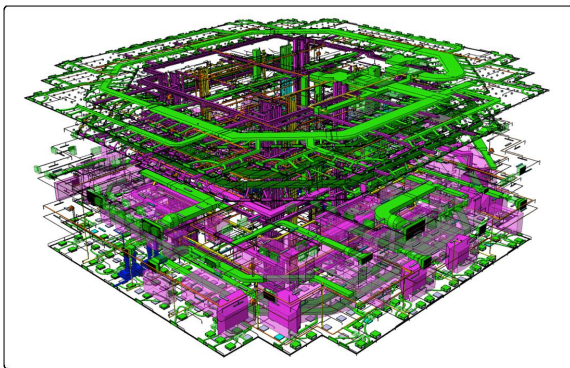
# Modern Buildings (Key Features)

Large-scale building systems are packed with automation:



# Modern Buildings (Key Features)

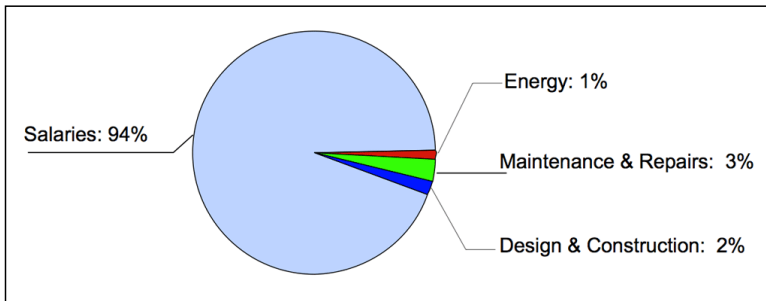
Large-scale building systems are intertwined networks of networks:



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**.

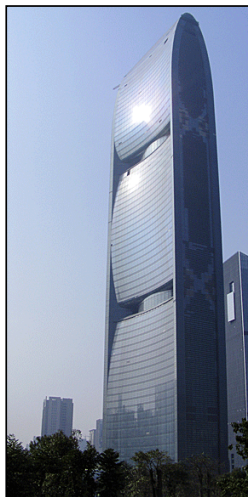
## Examples:

- 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)

## Systems of Systems Approach to Energy Efficiency Consider Buildings as Composition of Subsystems

Buildings Design  
Energy and Economic  
Analysis

Windows and Lighting

HVAC

Domestic/International  
Policies, Regulation,  
Standards, Markets

Demonstrations,  
Benchmarking, Operations  
and Maintenance



Natural Ventilation,  
Indoor Environment

Networks,  
Communications,  
Performance Database

Sensors, Controls,  
Performance Metrics

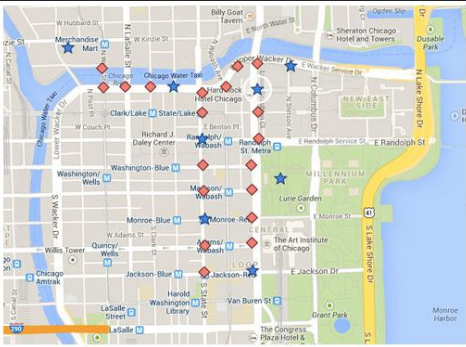
Power Delivery and  
Demand Response

Building Materials,  
Misc. Equipment

**Integration: *The Whole is Greater than the Sum of the Parts***

# 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

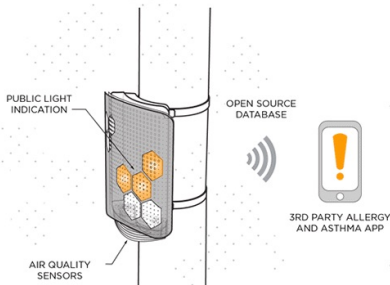
## What Data is Collected?

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.



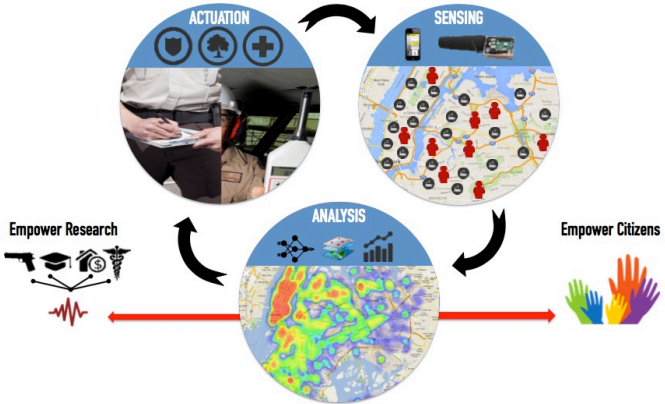
**Motivation.** Over 70 million people in US are exposed to noise levels beyond the limit of EPA considers to be harmful.

**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?

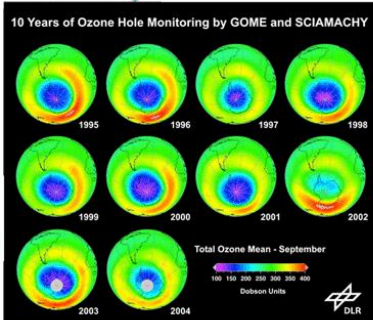
# NASA's Earth Observing System

## NASA'S EOSDIS → RE-NAMED EOS IN 2000



Drives innovation

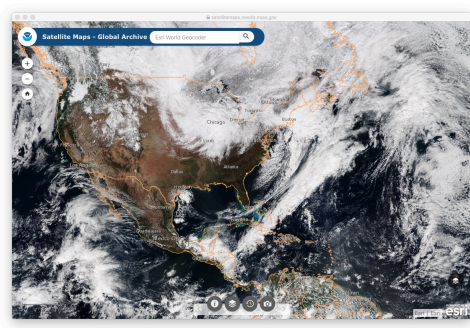
Enables science





# Satellite Imagery and Measurements

## Understanding Climate Change



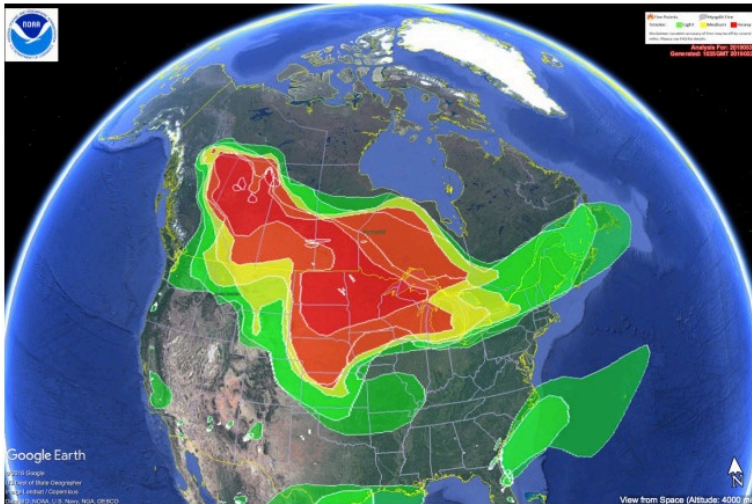
**Example.** Measure spatial and temporal extent of annual Snow Pack → Estimate water resources available for agriculture and urban consumption.

# 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 obscure 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 better 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 happening 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?

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