Active Heterogeneous Sensing for Fall Detection and Fall Risk Assessment

Skubic, Marjorie

Active Heterogeneous Sensing for Fall Detection and Fall Risk Assessment

M. Skubic, J. Keller, D. Ho, Z. He, M. Popescu & M. Rantz

ECE, HMI and Nursing, University of Missouri

CPS project that investigates the interplay of anomaly detection and the risk of anomaly events

Multi-camera vision (3D voxel model)

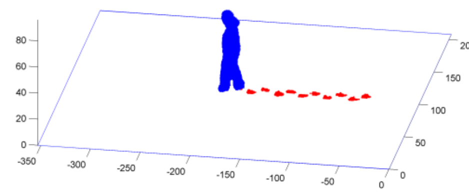
8-microphone circular array

PIR array

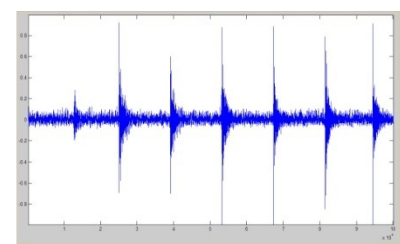
Detection history affects risk assessment

Fall Detection ⇄ **Fall Risk Assessment**

Risk factors affect detection



footsteps



CHALLENGES

- Unstructured, dynamic environments
- Low light, variable lighting
- Adaptive fusion of multi-scale signals with qualitative data and risk factors
- Privacy restrictions

CPS Grant CNS-0931607

Collaborative Research: Monitoring Human Performance with Wearable Accelerometers

Hodgins, Jessica; Mark Redfern; De la Torre

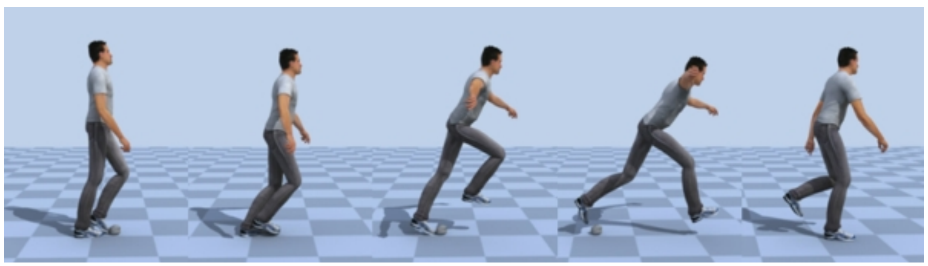
Carnegie Mellon
THE ROBOTICS INSTITUTE

Monitoring Human Performance with Wearable Accelerometers

Motivation:

Human-observer based methods for measuring human motion are labor intensive, and difficult to standardize across clinical settings or over time.

Many medical conditions are monitored only via short visits to the clinician.



Predicting risk of errors in gait

Mark Wilson/Getty Images

Parkinson monitoring

Exercise quality assessment for Knee osteoarthritis

Contributions:

Cyber physical systems for improved medical diagnosis and treatment monitoring

Several data collections underway (lab, assisted living)

New algorithms for time series classification

Impact:

Continuous and quantitative monitoring and evaluation of treatment at home.

Control Subject to Human Behavioral Disturbances

Patek, Stephen

Control Subject to Human Behavioral Disturbances:

Anticipating Behavioral Influences in the Control of Diabetes (CNS-0931633)

Stephen D. Patek (PI), University of Virginia

- This project addresses the design of control systems where the principle disturbances are the result of routine human behavior
  - Random, but not zero-mean white Gaussian
  - Statistical regular, but not periodic
- Goals:
  - To develop new mathematical models ("profiles") of human behavioral disturbances, focusing especially on appropriate statistical characterizations of routine behavior
  - To formulate and solve new control-theoretic problems that seek to anticipate human behavioral disturbances

- Principle Application:
  - <u>*Artificial Pancreas*</u> – feedback control of Type 1 Diabetes, where meals and exercise are the two main disturbances

(Wireless) Continuous Glucose Monitoring

Automated Closed-Loop Control

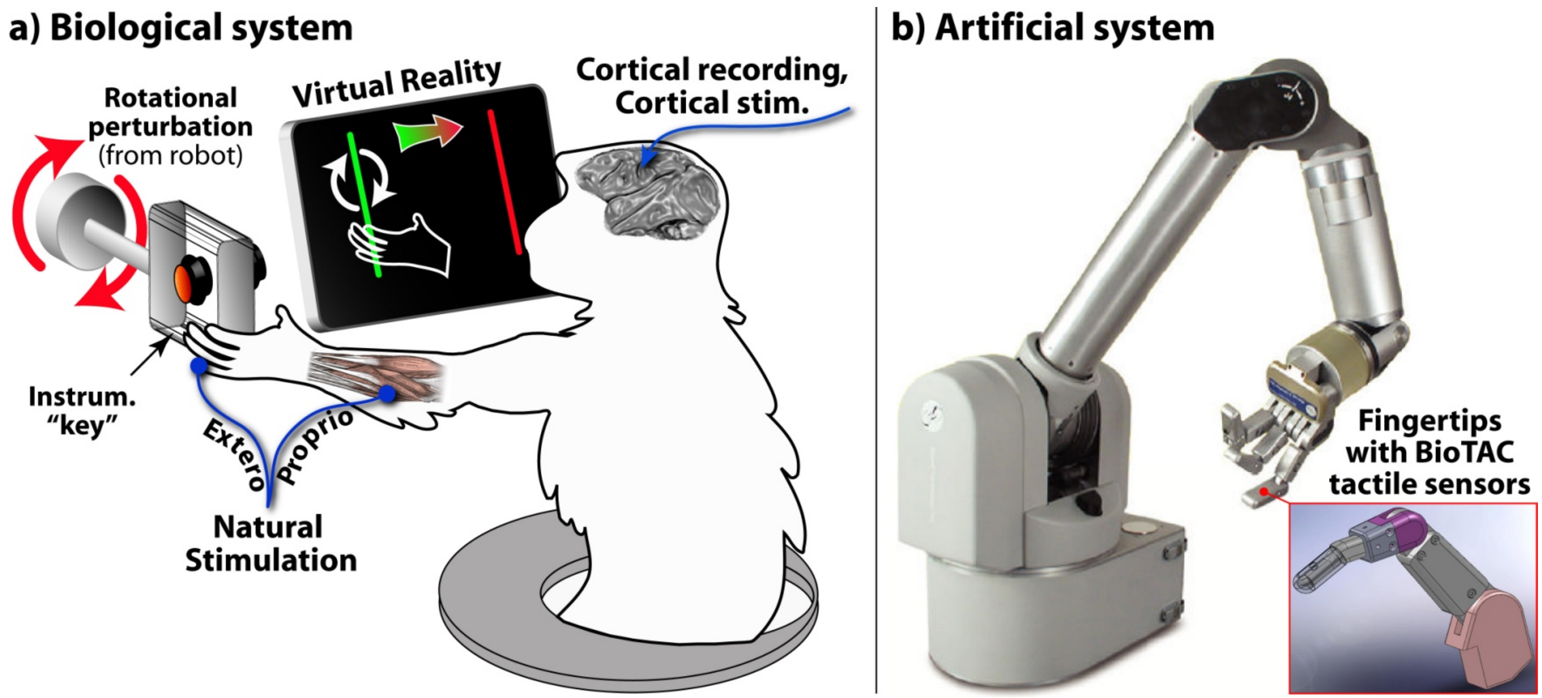
Continuous Subcutaneous Insulin Infusion (Insulin Pump)

Cyber-physical system challenges in man-machine interfaces: context-dependent control of smart artificial hands through enhanced touch perception and mechatronic reflexes

Santos, Veronica; Stephen Helms Tillery

CPS challenges in human-machine interfaces:

Context-dependent control of smart artificial hands through enhanced touch perception and mechatronic reflexes



1) **Establish relationships b/n biological and artificial systems** (perception and control)
2) **Induce perception of tactile feedback** through cortical stimulation
3) Develop algorithms for **smooth, context-dependent transfers of authority** between biological and artificial systems

Ira A. Fulton Schools of Engineering
ARIZONA STATE UNIVERSITY

Co-PIs: Veronica J. Santos and Stephen I. Helms Tillery

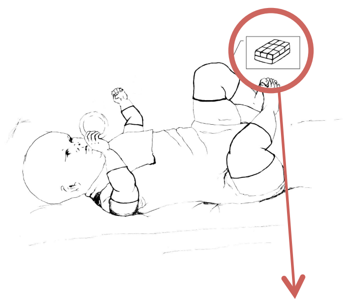
NSF Award #0932389

Programmable Second Skin to Re-educate Injured Nervous Systems

Goldfield, Eugene

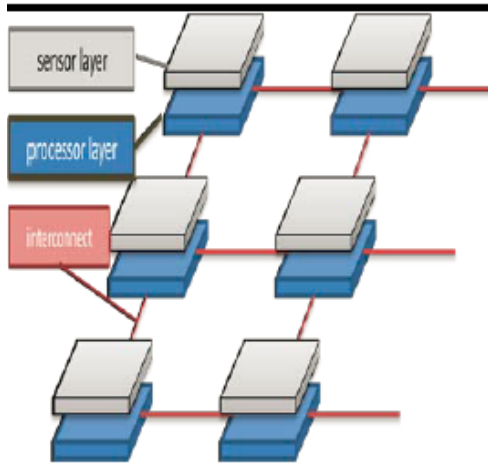
Programmable Second Skin for Re-Educating Injured Nervous Systems

Eugene C. Goldfield, Robert J. Wood, Dava Newman, Elliot Saltzman, Kenneth Holt
Marc Weinberg, Leia Stirling, Radhika Nagpal
Children's Hospital Boston, Wyss Institute For Biologically Inspired Engineering, Harvard University

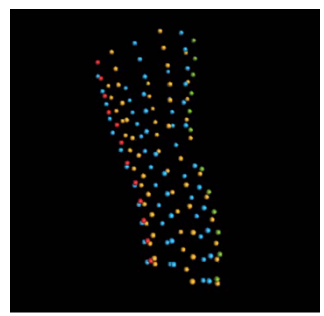


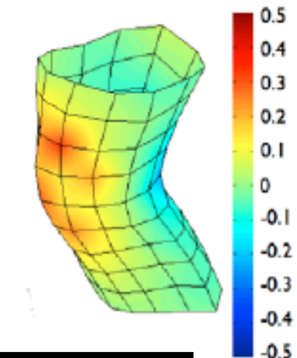
Use normally developing infant's kicking to inform a sensing and actuating "skin" that helps brain-injured infants improve and expand kicking motions

Stackable Physical Design

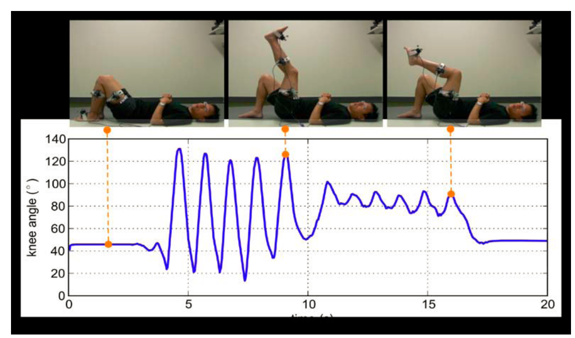


Advances in Strain-Field Analysis





Advances in Inertial Filtering



WYSS INSTITUTE
ANTICIPATORY MEDICAL DEVICES

Towards Neural-controlled Artificial Legs using High-Performance Embedded Computers

Huang, He

THE UNIVERSITY OF RHODE ISLAND

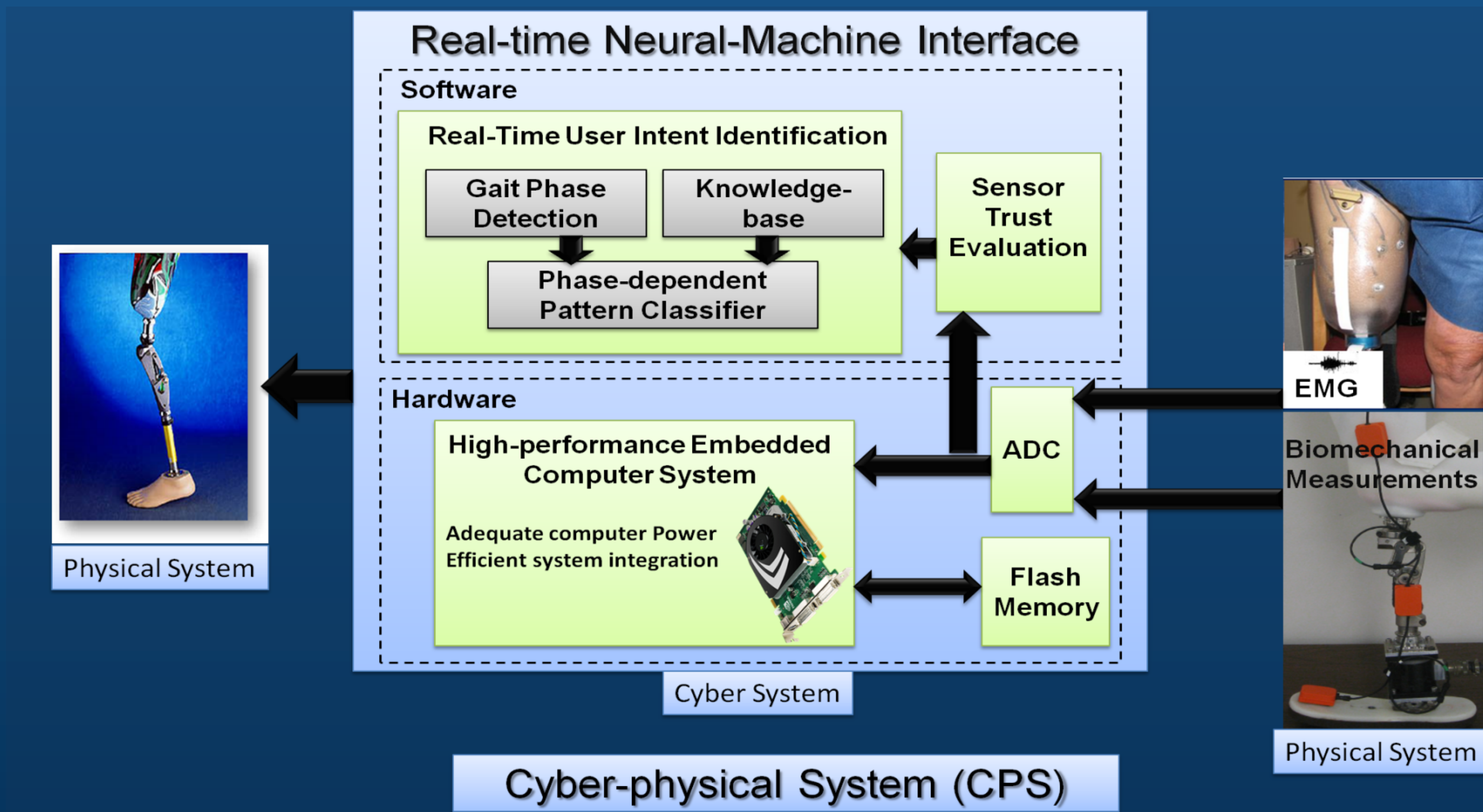
NSF/CPS:0931820

PI: He Huang, Co-PI: Yan Sun, Qing Yang

THINK BIG WE DO℠

Towards Neural-controlled Artificial Legs using High-Performance Embedded Computers

Objective: To develop a reliable and high-performance neural-machine interface (NMI) that accurately interprets the user's intended movements in real-time for neural control of artificial legs.



A Real-Time Cognitive Operating System

Ballard, Dana

A Real-time Cognitive Operating System

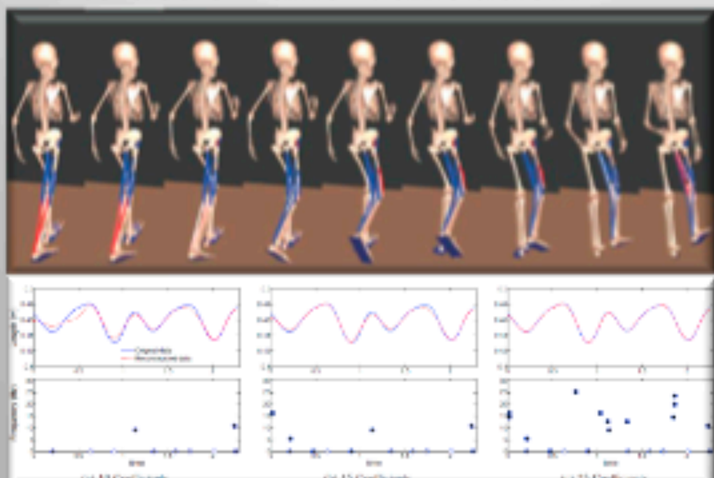
The University of Texas at Austin, Computer Science and Center for Perceptual Systems

Dana Ballard, Joseph Cooper, Rahul Iyer, and Dmitry Kit

Embodied Cognition and biologically inspired computational models

- Multiple levels of sensory representation, learning, and prediction
- Spatial and temporal hierarchical abstractions of tasks and functionality
- Human subjects for model extraction and validation

Computer models and human subjects in natural vision tasks.



Motor abstractions and sub-spaces.

Interactive control hierarchies.

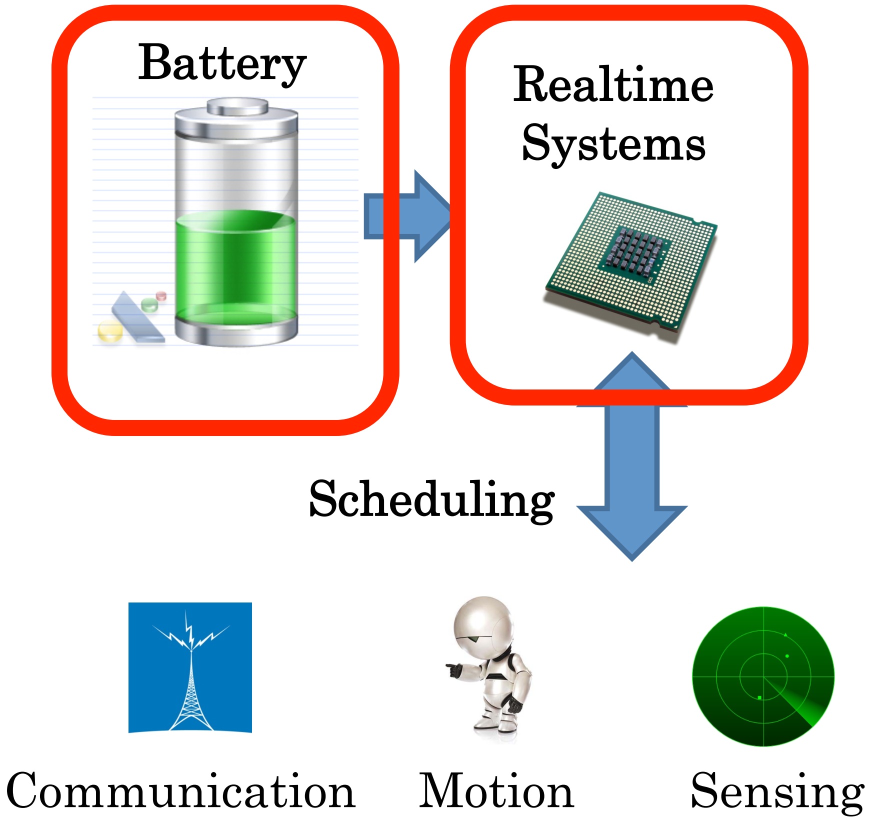
Cognitive sub-modules.

MPSoC based Control and Scheduling Co-design for Battery Powered Cyber-Physical Systems

Zhang, Fumin

Y1-Battery Powered CPS: Robustness

Establish a Unified Theoretical Foundation for Robustness of CPS



Work Completed

- Established a general hybrid systems model for any real-time scheduling algorithms.
- Introduced a novel concept of dynamic schedulability.
- Introduced a measure for robustness of scheduling algorithms.
- Developed a new criteria for battery failure based on stability theory.
- Introduced a measure for robustness of battery switching algorithms.
- Our analytical methods have advantage over computation methods.

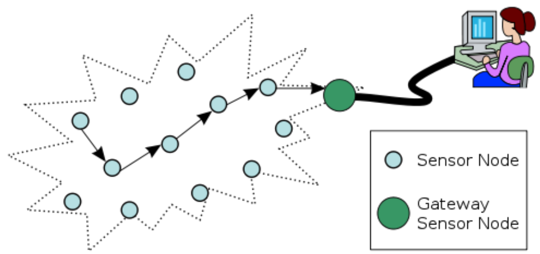
Non-Volatile Computing for Embedded Cyber-Physical Systems

Suh, Gookwon

Non-Volatile Computing

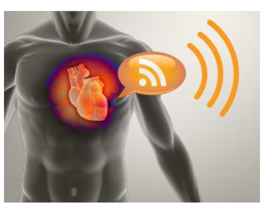
Wing-kei S. Yu, Shantanu Rajwade, Edwin C. Kan and G. Edward Suh
Cornell University

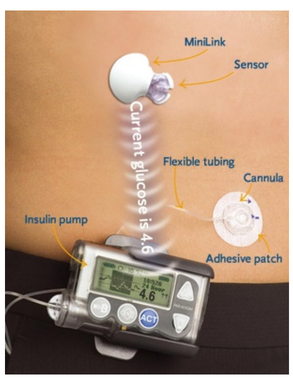
Embedded systems are everywhere



Autonomous wireless sensor networks

RFIDs and RFID readers



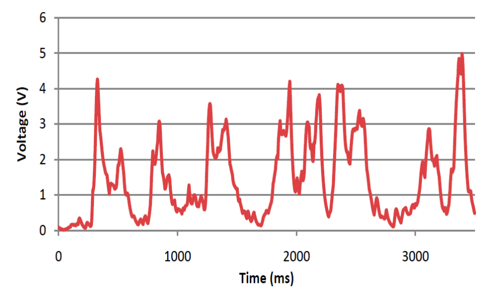


In-body sensors &
Health monitoring

Challenges:

Unstable power sources

Limited battery lifetime



Voltage trace from an RFID
Receiving radiated energy

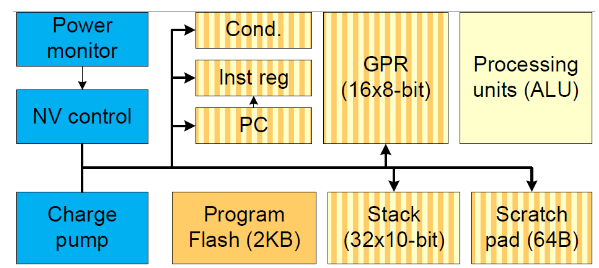
Can we eliminate dependence on batteries?

Non-volatile architecture enables:

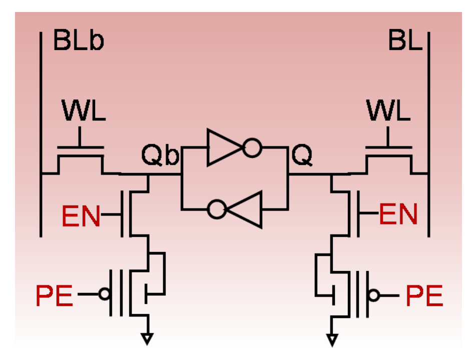
Computation across power outages

Idle time power saving

Fast checkpointing and recall



Non-volatile microcontroller block diagram.
Hashed areas indicate NV modification.



SRAM hybridized with non-volatile flash.

Programming Environment and Architecture for Situational Awareness and Response

Fowler, Robert

Productive Programming for Situational Awareness and Response

Rob Fowler (UNC-CH/RENCI)

Goal: Research on improving programming productivity for sensing and sense/react systems.

- •Productivity = Net present value of output.
    - •Efficient design and deployment
    - •Timely delivery of the right results.
- •QoS/Relevance constraints.

Driving Problems: Environmental Sense/React. Rapidly deployable, Robust, Real-time Situational Awareness and Response (R^3SAR Systems).

- •Response to environmental emergencies: fire, flood, wind, …
- •DHS and DoD problems.
- •Cost-effective sensing for field sciences.

General Approach: Explore/extend successful data-oriented, high-productivity methods.

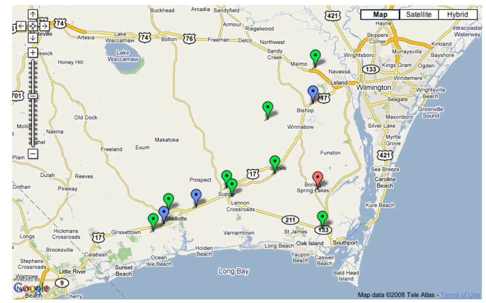
- •Spreadsheet (Table) idiom.
- •Map/Reduce → Sense/Reduce
- •Databases and extensions.
- •(Scripting languages.)

Specific Activities:

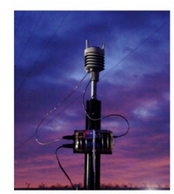
- •Experimental platforms:TelosB and Sunspots, embedded (MAEMO, Android, …) devices.
- •Software prototyping and experimentation.
    - •Sense/reduce prototype.
    - •Campus WiFi base station signal strength capture
    - •Control interface for "Tables" on Android phone.
    - •Bird feeder monitoring.

A Motivating Example: Flood Sensing in estuaries sensitive to storm surges (2007-2009)

RENCI and Brunswick County EMS.



- •Internet base stations (PC104/Linux) connected to EMS with failover using wired service, cellular modems, AV.25 on trunked EMS radio.
- •Results distributed via (Mobile) Web.
- •Base-station to sensor node (SunSpot) connectivity via wire, Bluetooth, Zigbee.
- •Sensors: flood level, robust weather stations.
- •Ample battery capacity with PV chargers.



Ant-Like Microrobots - Fast, Small, and Under Control

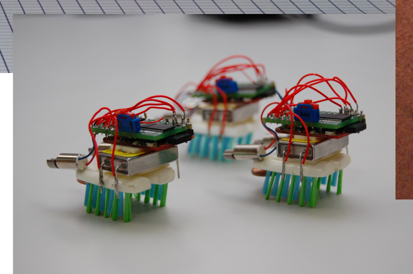
Martins, Nuno Miguel

CPS: Medium: Ant-Like Microrobots – Fast, Small, and Under Control

Pamela Abshire, Sarah Bergbreiter, Nuno C. Martins, Elisabeth Smela

Award 0931878, (10/01/2009 --- 09/30/2012)

- Objective: to develop the first wireless network of cooperative mobile autonomous robots at a very small scale. Main challenge: severe power, size and weight constraints
- Co-design approach to develop:
  - **Locomotion**:
    - Thermal bimorphs (legged chip sent for fabrication)
    - Micro-scale dielectric elastomer actuators (DEA)
  - **Control**: new decentralized coordination algorithms based on stochastic model predictive control principles.
  - **Computation**: Use low power hybrid hardware configuration.
  - **Testbed**:
    - Visual tracking
    - Fleet of Zigbots
    - Localization techniques



University of Maryland 1856

The Institute for Systems Research

Maryland Robotics Center

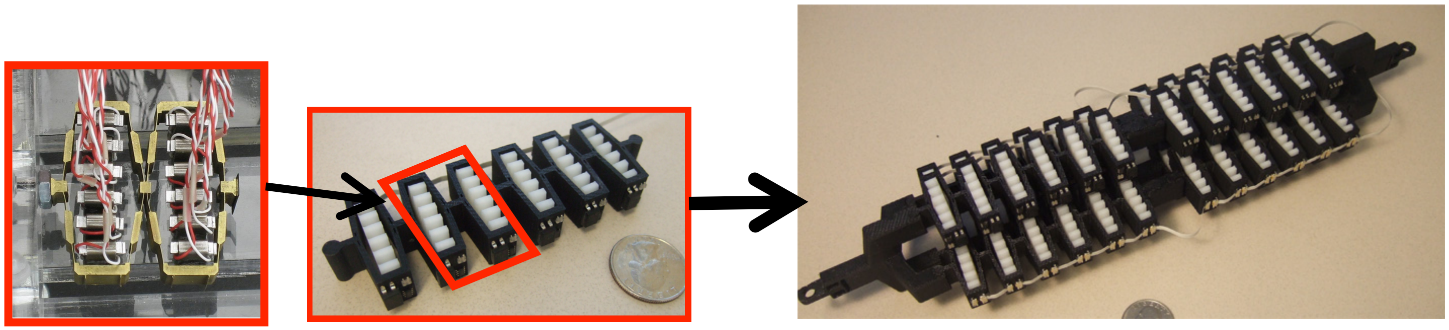
NSF CISE

Generation of natural movement for a multiple degrees-of-freedom robot driven by stochastic cellular actuators

Ueda, Jun

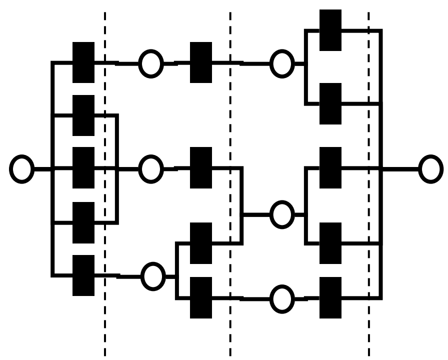
“Fingerprint” method for modeling and characterizing reconfigurable actuator array topologies

Jun Ueda, Georgia Institute of Technology ECCS-0932208



Piezoelectric actuator array

Connection

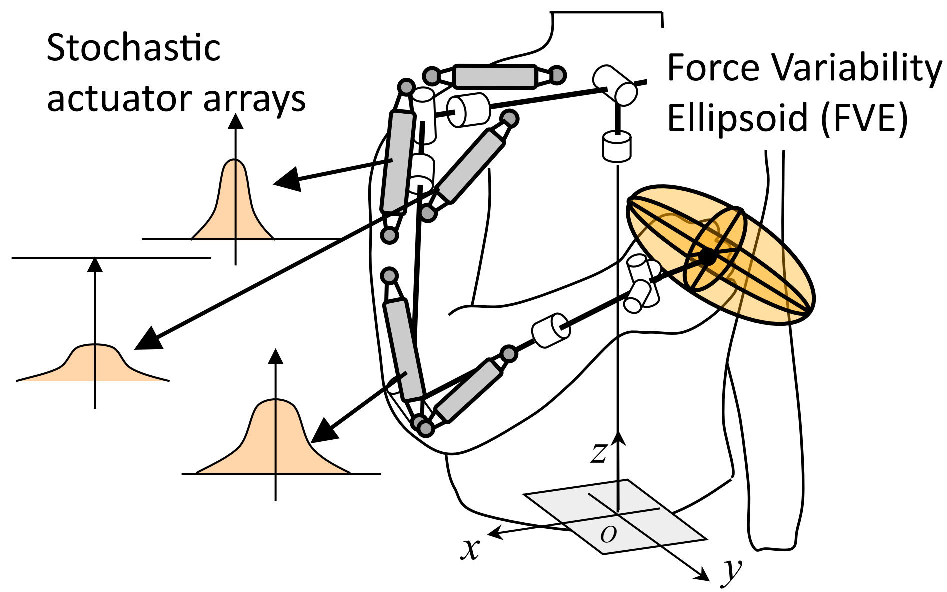


Fingerprint

$$\left[\begin{array}{c|ccc|ccc|c} \&1 & \&1 & \&E & \&10 & \&1 & \&6 & \&8 & \&1F \\ 5 & 1 & 1 & 2 & 2 & 2 & 1 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 \end{array}\right]$$

L1 L2 L3 L4

Generation of “natural” robot movements



Actuator-level variability analysis

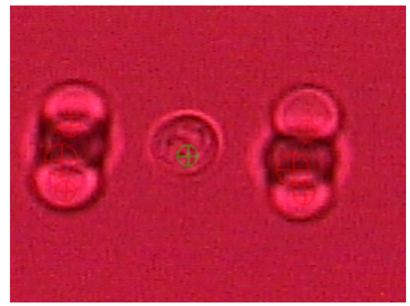
Image Guided Autonomous Optical Manipulation of Cell Groups

Gupta, Satyandra

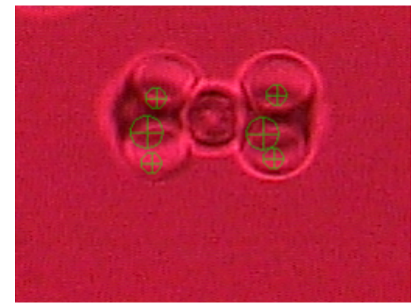
Image Guided Autonomous Optical Manipulation of Cell Groups

Satyandra K. Gupta and *Wolfgang Losert*

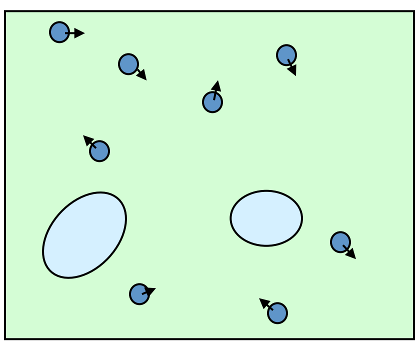
- Create computational foundation, methods, and tools for efficient and autonomous optical micromanipulation using microsphere ensembles as grippers



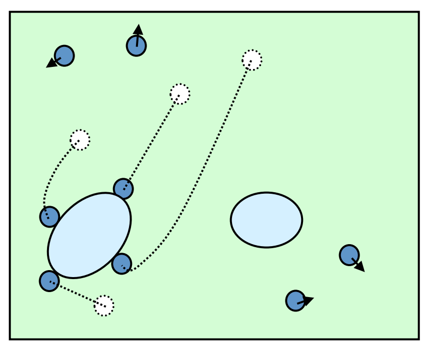
Initial location of grippers



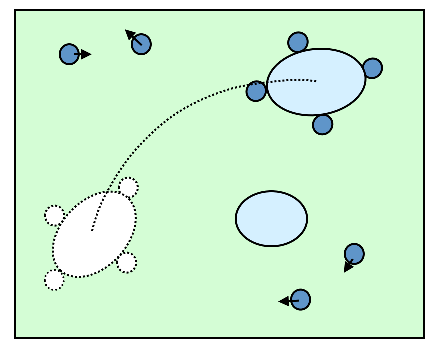
Trapped Cell



Initial scene



Four microspheres are moved to trap the cell



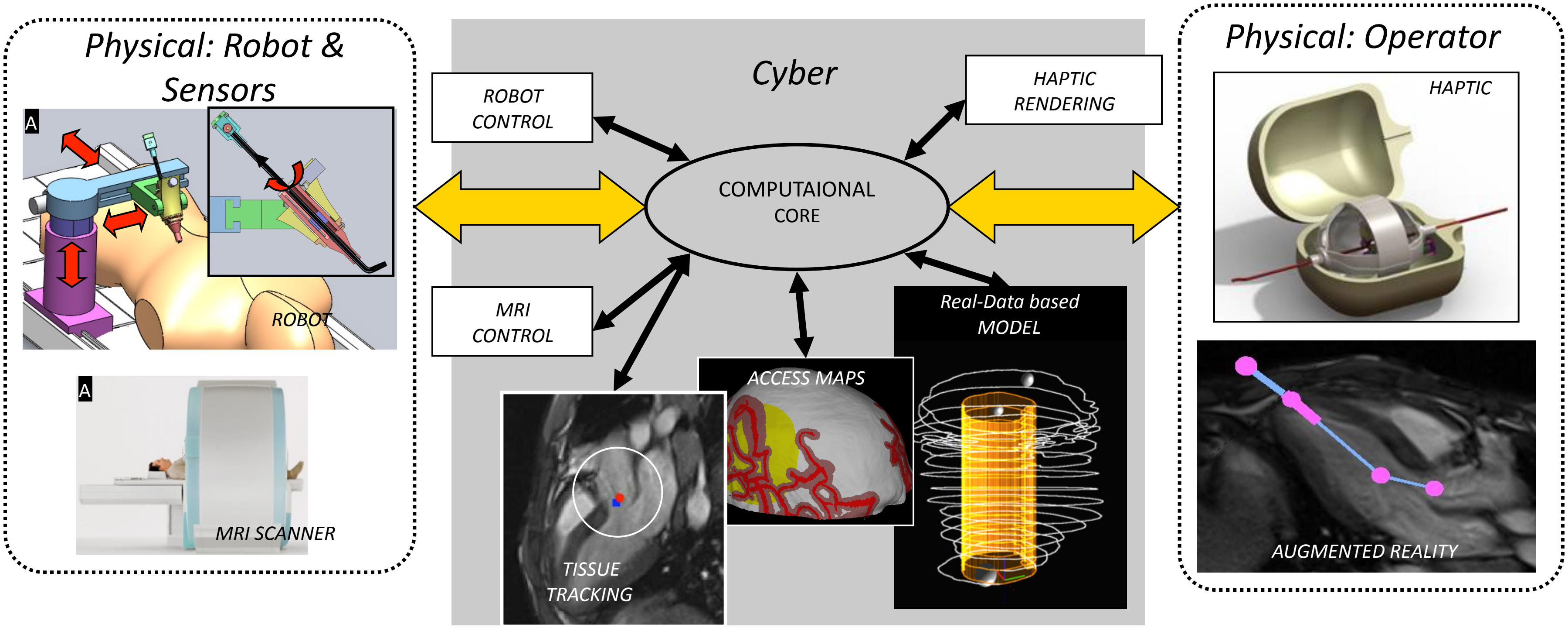
Trapped cell is move to the desired location

Image Guided Robot-Assisted Medical Interventions

Tsekos, Nikolaos

Award Number: 0932272
Image Guided Robot-Assisted Medical Interventions

PI: Nikolaos V. Tsekos; Co-PI: Zhigang Deng, Karolos Grigoriadis, Ioannis A. Kakadiaris, Javad Mohammadpour.



The scientific directions, and the associated specific research objectives, of the Multimodal Image-guided RObot-assisted Surgeries (MIROS) project is its reliance on *true sensing* of the *physical world* with multi-contrast imaging and distributed force/bending-sensors, in order to maneuver a steerable surgical robotic manipulator inside the continuously changing environment of a patient while offering a comprehensive perception of the Area of Operation (AoO) to the operator via a visuo-haptic interface.

Learning for Control of Synthetic and Cyborg Insects in Uncertain Dynamic Environments

Abbeel, Pieter

Learning for Control of Synthetic and Cyborg Insects in Uncertain Dynamic Environments

Pieter Abbeel (PI), Ron Fearing, Michel Maharbiz --- UC Berkeley

Cyborg beetle

Synthetic crawler

Objective

Development of learning and adaptation capabilities that will enable operation of synthetic and cyborg insects in complicated environments, such as collapsed buildings.

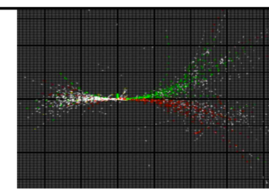
Technical Approach

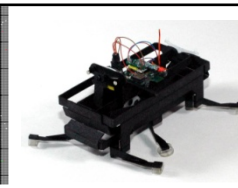
(i) Online performance improvement from minimal experience.

(ii) Learn control policies and dynamics models through sharing across platforms and environments.

(iii) Control learning algorithms on low-cost, low-power platforms.

Year 1 Results





Cyborg beetle:
Hardware/software setup, initial flight data

Synthetic crawler:
On-board electronics: video, gyro, accel.

Learning and adaptation:
Model-free policy gradient like method that leverages past experience for improved learning performance.

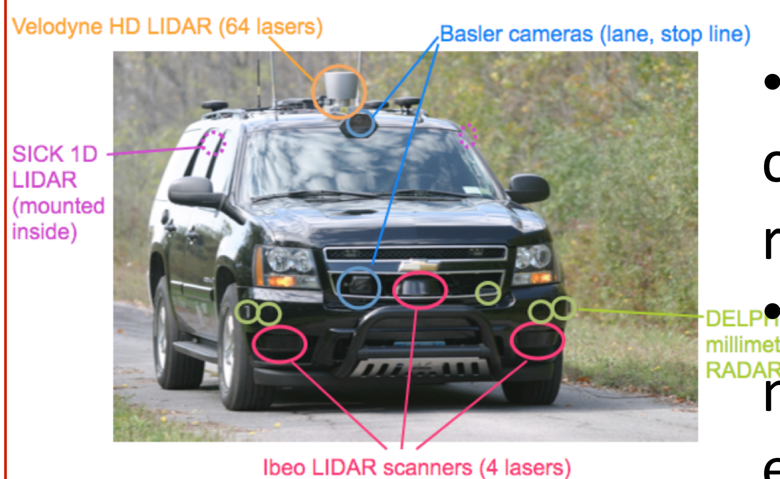
Tightly Integrated Perception and Planning in Intelligent Robotics

Mark Campbell, Dan Huttenlocher,
Hadas Kress-Gazit

Tightly Integrated Perception and Planning in Intelligent Robotics

Mark Campbell, Dan Huttenlocher, Hadas Kress-Gazit
Cornell University

Objective: Tightly integrates probabilistic perception and deterministic planning in a formal, verifiable framework



- ***Representations*** – new techniques for constructing and maintaining representations of dynamic environments.
- ***Anticipation and Motion Planning*** - methods to anticipate changes in the environment and use them as part of the planning process.
- ***Verifiable Task Planning*** - providing probabilistic guarantees for high-level behaviors.

Collaborative Research:Localization and System Services for SpatioTemporal Actions in Cyber-Physical Systems

Arora, Anish; Gupta, Rajesh

Localization and System Services for SpatioTemporal Actions in Cyber-Physical Systems

Prof. Anish Arora (Co-PI: Ohio State University), Prof. Rajesh Gupta (Co-PI: UC San Diego), Dr. Ryo Sugihara (UC San Diego)

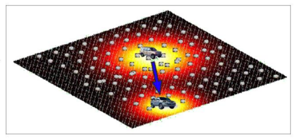
A Focus on Deterministic Properties

Sensed data is typically profiled in terms of statistical properties
- Focus is on efficiency of learning/testing of statistics

But for CPS applications, safe/critical operation often demands deterministic properties
- Our focus is on worst-case bounds on spatiotemporal properties
  i.e., network time, node location, state latency / error/ rate

Example: Pursuer-Evader Control System

Executing on pursuer — Tracking Control Application
Executing on network — Synchronized Location Snapshots



Control Properties Depend on Deterministic Guarantees

For single-pursuer single-evader catch-me game,
Nash equilibrium strategy exists *provided*
deterministic guarantees exist on snapshot latency, error, and rate

Theorem:

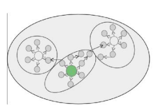
Given
- distance $d_{pe}(t)$ between pursuer p & evader e
- speed ratio $\alpha = v_p/v_e$
- error $z(t)$ in distance estimate
- staleness $\delta(t)$ in the state snapshot
- synchronization interval $r(t)$ between snapshots

Eventual catch guaranteed if there exists $k > \frac{\alpha+1}{\alpha-1}$ s.t.
- distance sensitive latency: $\delta(t) < \frac{d_{pe}(t)}{v_e}\left(1 - \frac{\alpha+k+1}{\alpha k}\right)$
- distance sensitive error: $z(t) < \frac{d_{pe}(t)}{k}$
- distance sensitive rate: $r(t) < \frac{d_{pe}(t)}{v_p}\frac{k+1}{k}$

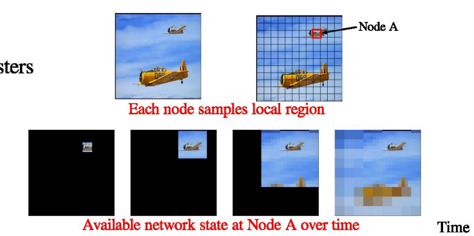
Algorithms and Techniques for System Services with Deterministic Accuracy Guarantee

- Distance Sensitive Snapshot Service

- Clustering
  + Solid disk clustering with or without localization
  + Stretch factor gives local healing
  + Extended to log(N) levels



- Scheduling
  + Aggregate and disperse data along trees in clusters
  + At each level
    - Clusterhead compresses data into m bits
    - Summary dispersed to all nodes in cluster & its neighboring clusters
  + Pipelined implementation
    - Nodes generate fresh data as soon as previous data out of level-1 clusters

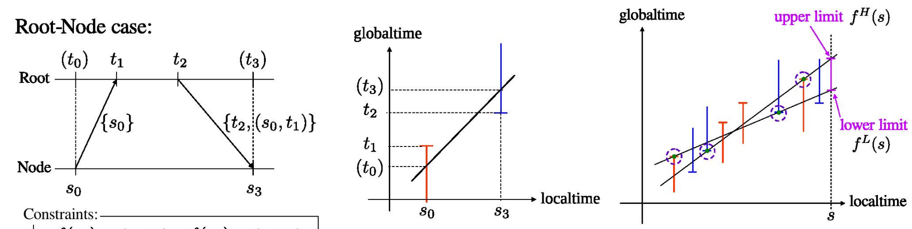


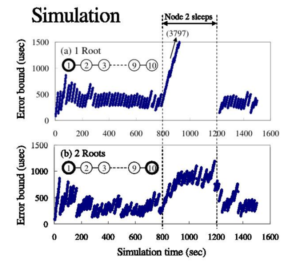
Each node samples local region

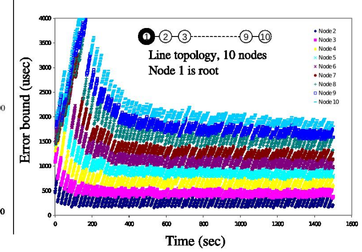
Available network state at Node A over time

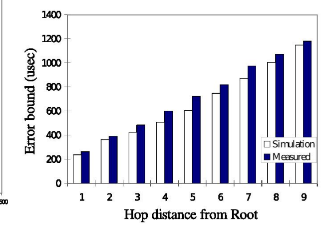
- Clock Synchronization

- Use causality in messaging to obtain constraints on global time
- Synchronization error bounds derived from multiple constraints



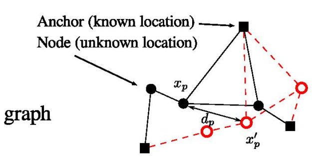






- Sensor Localization

- Sensor localization as (nonconvex) optimization problem
- Upper bound of localization error by SDP relaxation

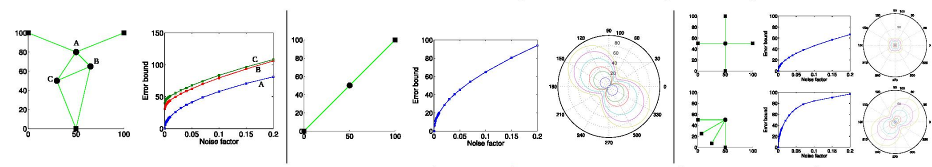


Formulation idea: Distance of nodes in two different realizations of a graph

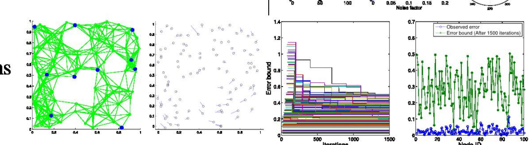
Maximize $||x'_p - x_p||(= d_p)$

s.t. - distance between nodes: $||x_i - x_j||^2 = d_{ij}^2, \forall(i,j) \in E_n$ $\quad ||x'_i - x'_j||^2 = d_{ij}^2, \forall(i,j) \in E_n$

- distance between node and anchor: $||x_j - a_k||^2 = d_{jk}^2, \forall(j,k) \in E_a$ $\quad ||x'_j - a_k||^2 = d_{jk}^2, \forall(j,k) \in E_a$



Iterative algorithm for large networks
- Further relaxation: Solve SDP for subgraphs
- Increase the size of subgraph to improve error bounds



Dynamically Managing the Real-time Fabric of a Wireless Sensor-Actuator Network

Lemmon, Michael

Dynamically Managing the Real-time Fabric of a Wireless Sensor-Actuator Network

- CNS-09-31195 September 1, 2009 – August 31, 2012
- University of Notre Dame: M. Lemmon (PI), X.S. Hu (Co-PI)

- **Objective:** develop algorithms for wireless sensor-actuator networks (WSAN) supporting control applications that with hard/firm real-time quality-of-service (QoS) constraints.

- **Approach:** To meet real-time constraints required in networked control applications, one must manage the communication network's "real-time fabric" to enable reliable prediction of end-to-end delays. This will be done by stabilizing the network's interference environment through adaptive power/channel control, by managing data dropouts through rate control, and the use of anytime controllers. This approach balances the relationship between application (physical) performance and a network's (cyber) end-to-end QoS. This requires a scalable integration of methods used in control, wireless networking, and real-time systems.

- **Progress to Date:**
  - Reducing jitter in real-time control tasks (RTSS09, ECRTS10)
  - Bounded Burst QoS constraints on dropouts (ACC 10, TAC 2010)
  - Adaptive bandwidth reservation schemes in wireless networks (TMC 2010)
  - Distributed Algorithms for Network Optimization (Ph.D. Dissertation 2010)

Sensor Network Information Flow Dynamics

Khandani, Mehdi

Sensor Network Information Flow Dynamics

PI: Mehdi Kalantari Khandani

- Optimum information flow in wireless sensor networks become computationally prohibitive when the number of nodes grows large.
- Instead of modeling the network as a discrete nodes, the wireless sensor network can be modeled as a continuum of nodes covering an area (namely A) in R^2 plane.
- In a dense wireless network, information can be treated like a fluid. **Information flow vector field, *D*,** satisfies the following equations:

$$\nabla \cdot D = \rho(z) \quad z \in A$$

$$D \cdot n = 0 \quad z \in \partial A$$

$$D^* = \arg\min \int_A \| D(x,y) \|^2 \, dxdy$$

$$\Rightarrow \nabla \times D^* = 0 \Rightarrow D^* = \nabla u$$

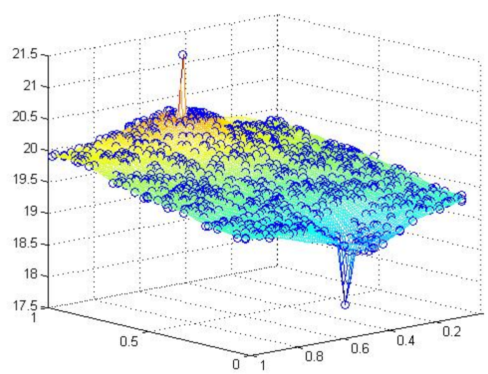
- Potential function u satisfies Poisson's equation:

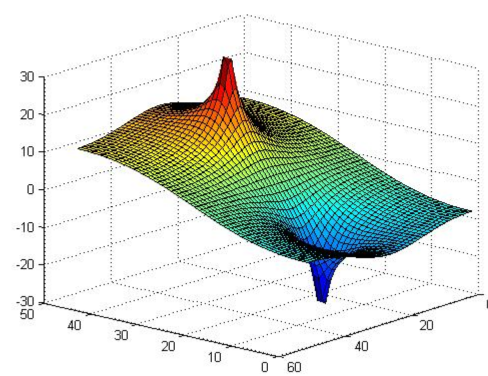
$$\nabla^2 u = \rho(z) \quad z \in A$$

$$\frac{\partial u}{\partial n} = 0 \quad z \in \partial A$$

- Using Gauss Harmonic Theorem a distributed solution of this PDE on a stochastic grid is calculated using:

$$\hat{u}(z) = \frac{1}{M} \sum_{i=0}^{M-1} u(z_i) - \frac{E[r^2]}{4} \rho(z)$$



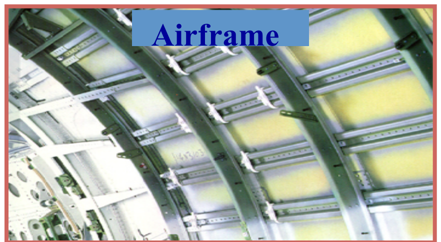


A Unified Distributed Spatiotemporal Signal Processing Framework for Structural Health Monitoring

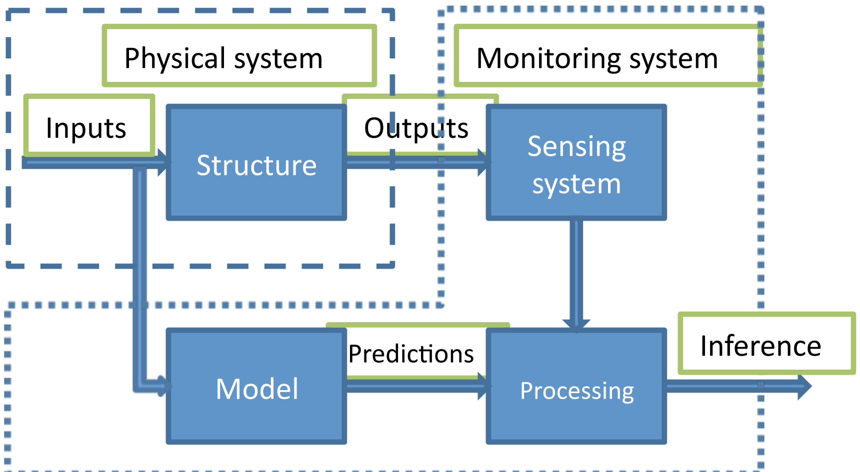
Cheng, Qi

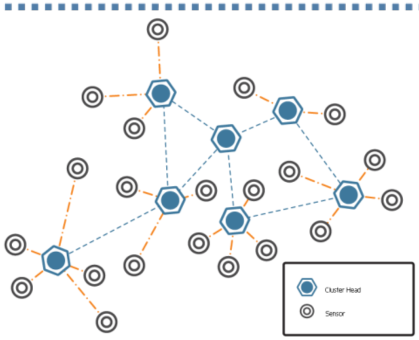
A Unified Distributed Spatiotemporal Signal Processing Framework for Structural Health Monitoring

PI: Qi Cheng, School of Electrical and Computer Engineering, Oklahoma State University



Photonic Crystal Sensing Fiber





Motivation:

• This research is motivated by the current inability to accurately detect, diagnose or prognose structural anomalies/damages at an early stage.

•The critical gap from prior domain knowledge of physical systems and large amount/diverse sensor observations to the improved accuracy and confidence in health state assessment should be addressed.

Objective:

To develop a collaborative signal processing framework by coupling sensing data with physics-based and data-driven models to detect and diagnose degradation and damages.

Technical Approach:

• Model identification based on the domain information and Markov random field modeling;

•Distributed and localized inference by taking advantage of spatiotemporal information represented by the model;

•Design of a cyber-physical system for structural health monitoring through optimizing the sensing system, including what/where/how to sense.

Embedded Fault Detection for Low-Cost, Safety-Critical Systems

Balas, Gary

Embedded Redundancy Management for Low-Cost, Safety-Critical Systems

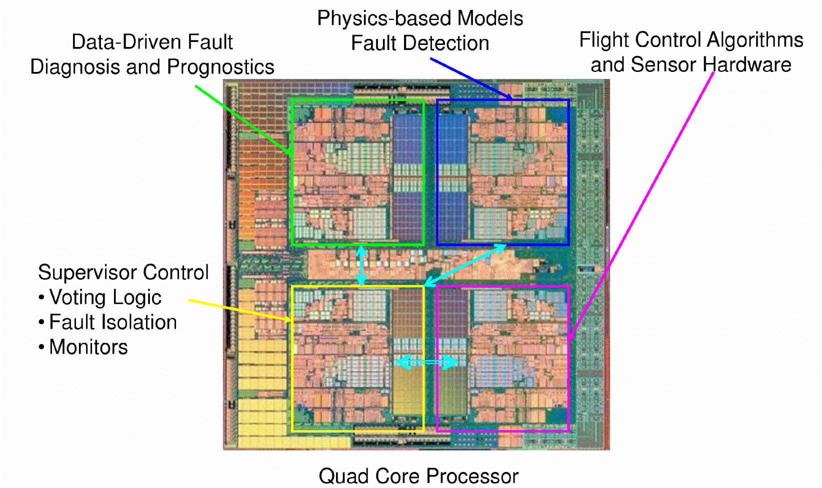
Seiler, Balas, Heimdahl, Srivastava, and Zhai

Issue: Current safety critical systems rely mainly on physical redundancy, increases system size, complexity and power.

Objective: Develop algorithms and computing architectures which enable fault detection without relying on physical redundancy.

Fault Detection Approach

1. *Model-based monitors* to detect faults in physical domain
2. *Monitors derived from software requirements* to detect faults in cyber (hardware/software) domain
3. *Data-driven anomaly detection* to cyber/physical faults



Computing Architectures:
- Multi-core architectures

Applications:
- UAVs, medical devices, road vehicles

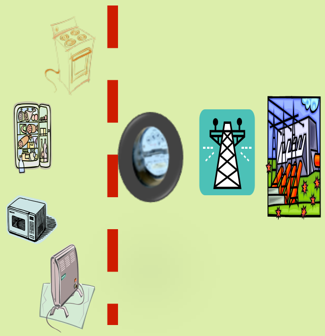
A Framework for Enabling Energy-Aware Smart Facilities

Soibelman, Lucio

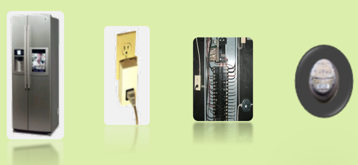
Enabling Energy-Aware Smart Facilities

Lucio Soibelman[1], H. Scott Matthews[1], José M. F. Moura[2], Mario Berges[1], Yuanwei Jin[3]
[1]Civil and Environmental Engineering Department, [2]Electrical and Computer Engineering Department, Carnegie Mellon University
[3]Department of Engineering and Aviation Sciences, University of Maryland Easter Shore

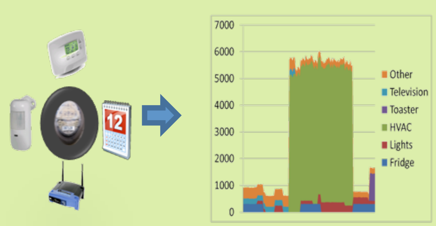
Problem Description



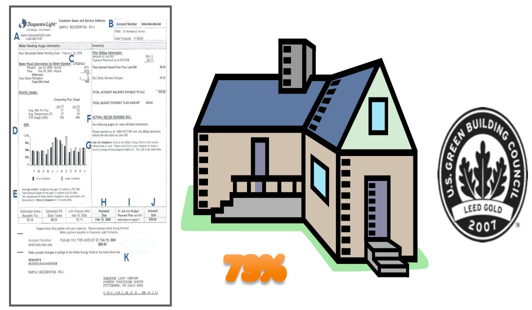
The demand is mostly ignored. Feedback helps reduce.



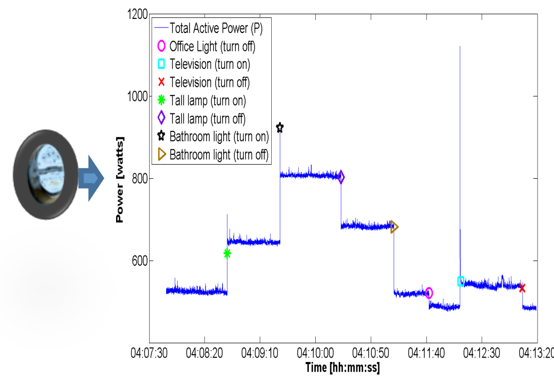
Difficult to obtain appliance-level data

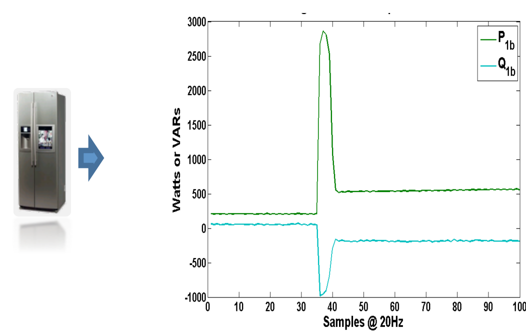


Can we leverage low-cost data sources?

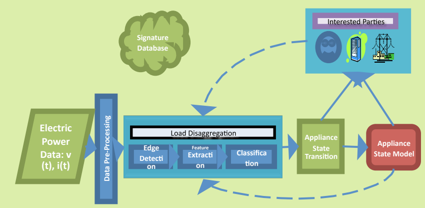


Of U.S. electricity consumption

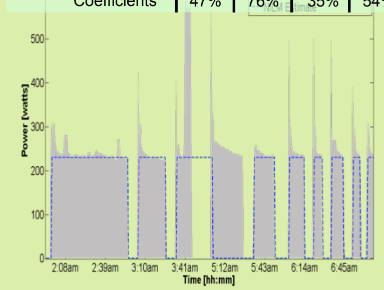




Solution and Results



Validation Results (Accuracy in %)		GNB	kNN, k=1	Ada Boost	DT
Laboratory (A)	Delta	52%	67%	**51%**	61%
	Whole Transient	38%	73%	--	58%
	Polynomial Coefficients	58%	67%	**51%**	52%
	Fourier Coefficients	64%	**79%**	2%	**64%**
	RBF Coefficients	**67%**	67%	**	**64%**
House (B)	Delta	47%	73%	36%	42%
	Whole Transient	9%	73%	--	47%
	Polynomial Coefficients	**61%**	**80%**	**61%**	**57%**
	Fourier Coefficients	50%	**80%**	55%	54%
	RBF Coefficients	47%	76%	35%	54%



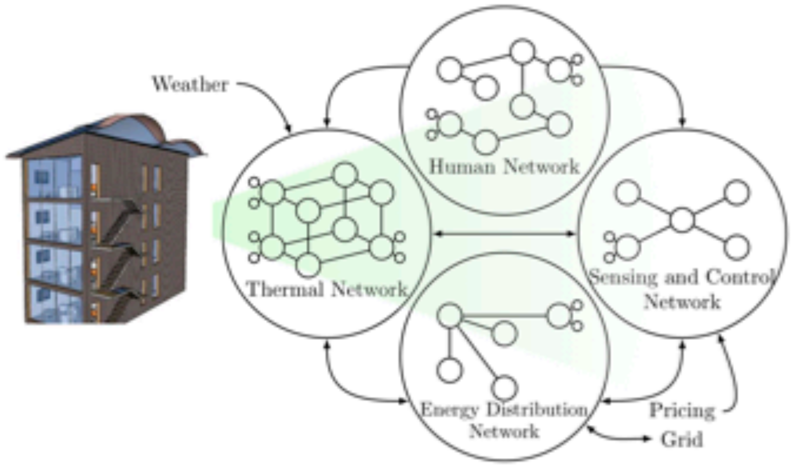
Cyber-Enabled Efficient Energy Management of Structures (CEEMS)

Vincent, Tyrone

CEEMS – Cyber Enabled Energy Management of Structures

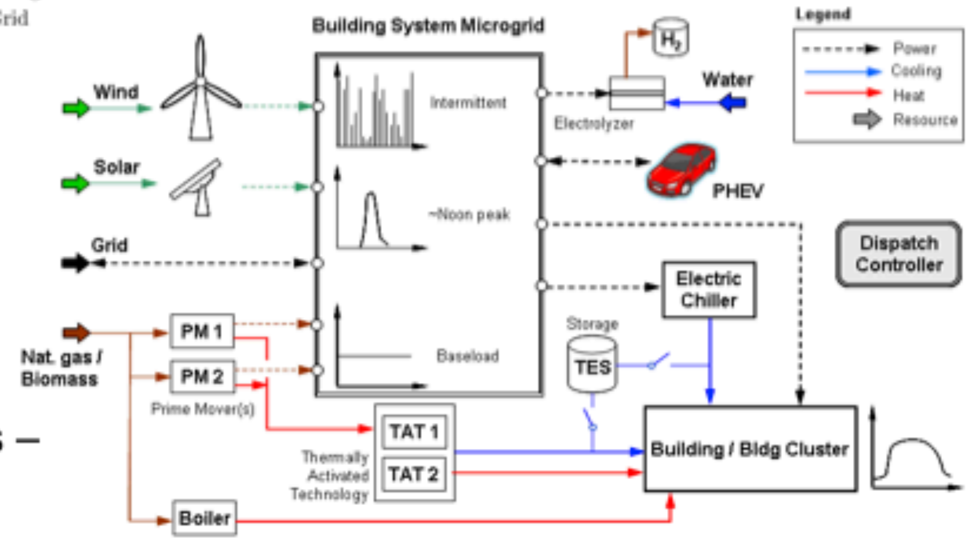
Tyrone Vincent, Robert Braun, Dinesh Mehta, Kevin Moore, Sid Suryanarayanan, Marcelo Simoes, William Hoff

Supported by NSF Grant CNS-0931748



Application area: Buildings as cyber-physical systems with multiple, interacting networks

- Simulation and Optimization for Buildings and Integrated Energy Systems
- Cyber Enabled Building Energy Management Systems
- Activity Recognition
- Interconnected Dynamic Systems – Identification and Control



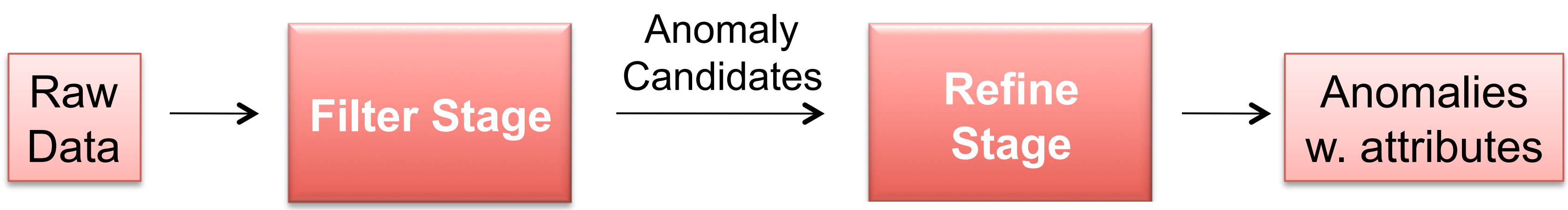
Anomaly Detection

Han, Jiawei

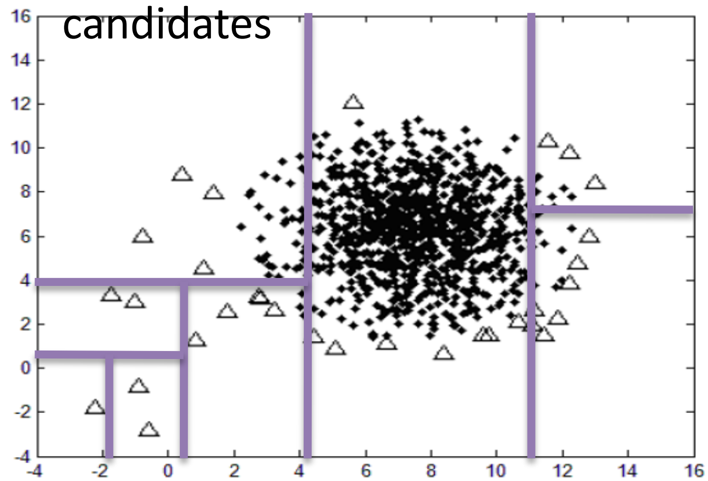
Anomaly Detection: A Filtering-and-Refinement Approach

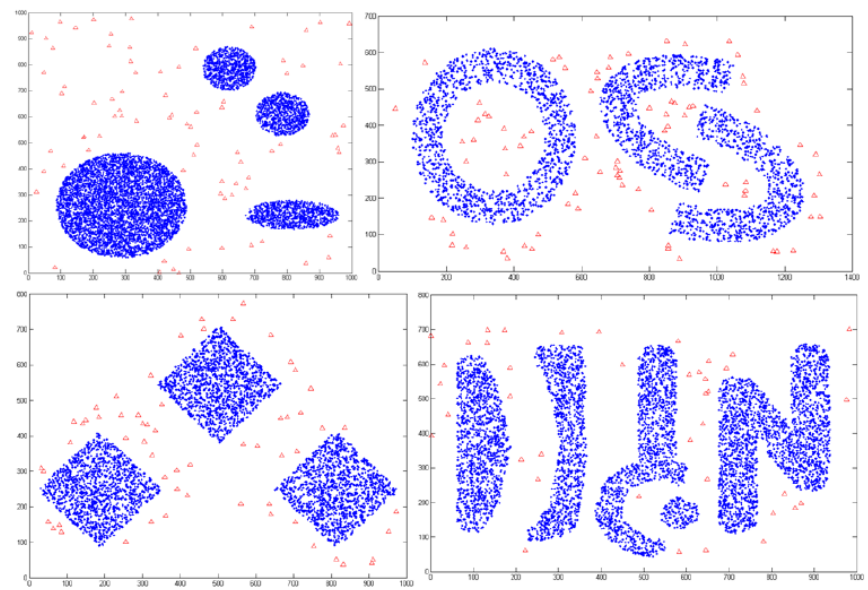
Efficient detection of abnormal events!

- Method
  - Filtering: Eliminate obvious normal data (Roughly separate normal from abnormal, by *Deterministic Space Partition*, and generate a small set of anomaly candidates)
  - Refinement: then focus on possible anomalies



- Scan dataset once, with linear time, generate a small set of anomaly candidates

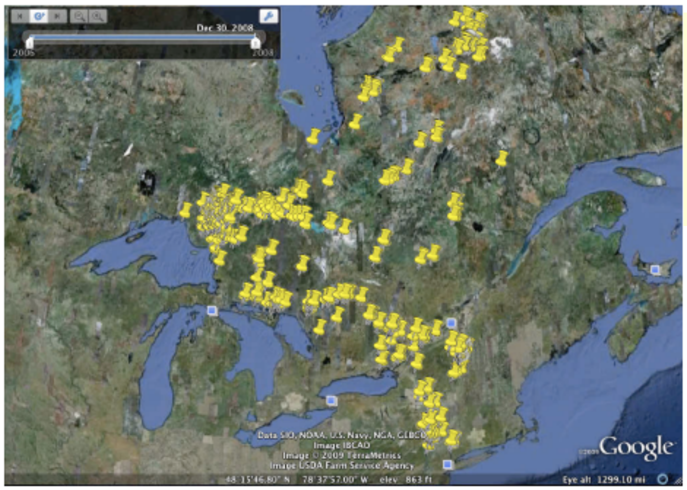




Outliers are identified (marked red) in the data

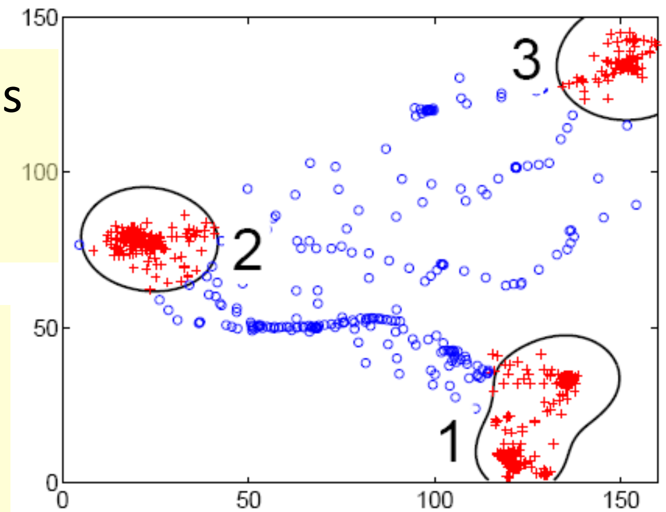
Discovery of Periodic Patterns of Moving Object Clusters

- A system that mines moving object patterns: Z. Li, et al., "MoveMine: Mining Moving Object Databases", SIGMOD'10 (system demo)
- Z. Li, B. Ding, J. Han, and R. Kays, "Mining Hidden Periodic Behaviors for Moving Objects", KDD'10 (sub)

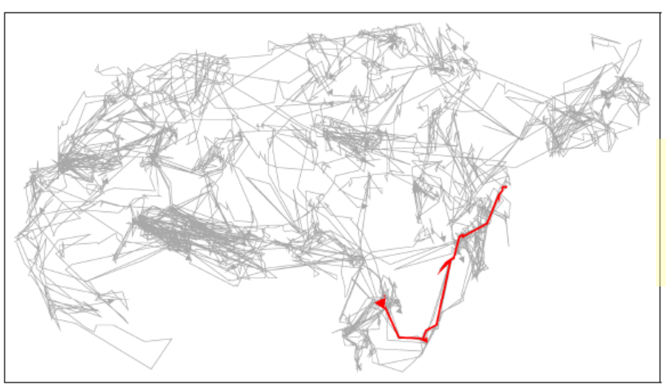


← Bird flying paths shown on Google Earth

Mined periodic patterns by our new method →

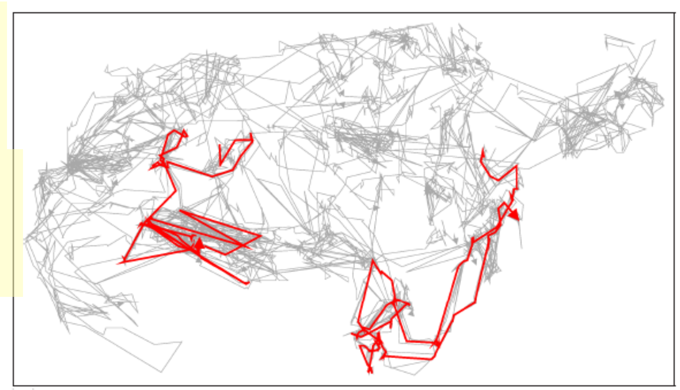


- Z. Li, B. Ding, J. Han, and R. Kays, "Swarm: Mining Relaxed Temporal Moving Object Clusters", VLDB'10 (sub)



Swarm discovers more patterns →

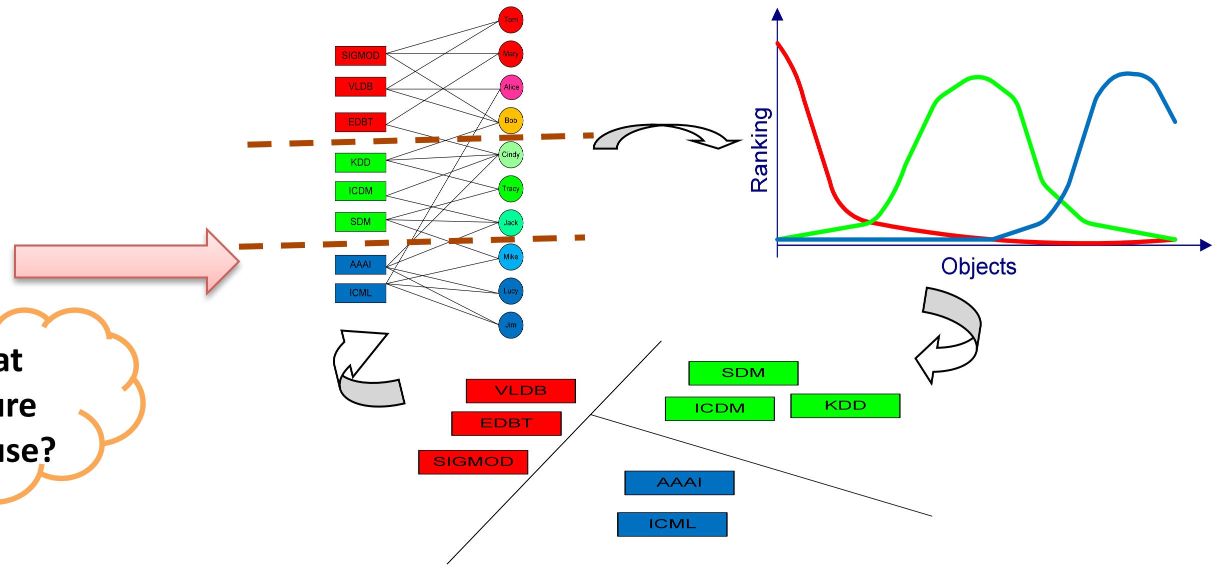
← **Convoy** discovers only restricted patterns



Foundation of Heterogeneous Information Networks (KDD'09, PKDD'10)

Global Ranking?

Clustering in heterogeneous network?



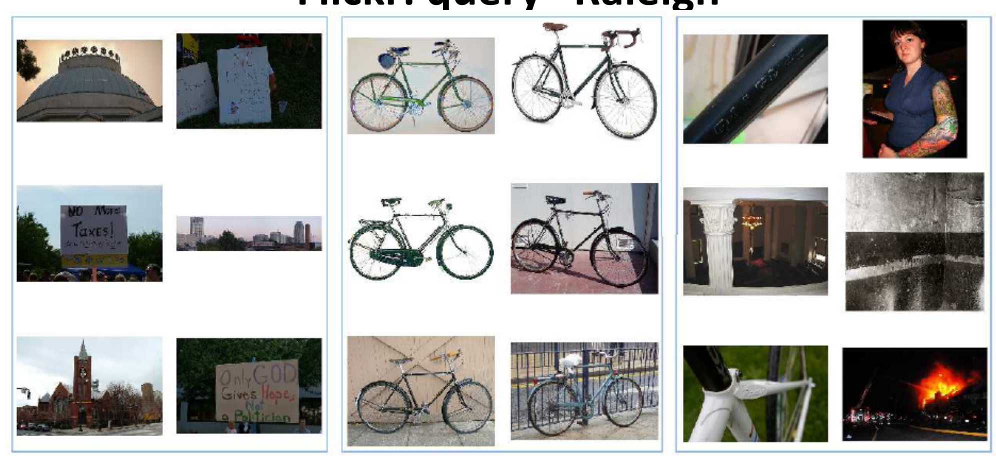
Cluster and rank people or events
Find highly suspicious groups/events

DBLP

Table 5: Top-10 Conferences in 5 Clusters Using RankClus

	DB	Network	AI	Theory	IR
1	VLDB	INFOCOM	AAMAS	SODA	SIGIR
2	ICDE	SIGMETRICS	IJCAI	STOC	ACM Multimedia
3	SIGMOD	ICNP	AAAI	FOCS	CIKM
4	KDD	SIGCOMM	Agents	ICALP	TREC
5	ICDM	MOBICOM	AAAI/IAAI	CCC	JCDL
6	EDBT	ICDCS	ECAI	SPAA	CLEF
7	DASFAA	NETWORKING	RoboCup	PODC	WWW
8	PODS	MobiHoc	IAT	CRYPTO	ECDL
9	SSDBM	ISCC	ICMAS	APPROX-RANDOM	ECIR
10	SDM	SenSys	CP	EUROCRYPT	CIVR

Flickr: query "Raleigh"



- RankClus/NetClus: Integrating Clustering with Ranking for Heterogeneous Information Network Analysis (KDD'09)
- GNetMine: Classification of Heterogeneous Information Networks (PKDD'10)

Towards Foundations of Cyber-Physical Networks

- Principles for mining moving objects and spatiotemporal data
- Principles for mining heterogeneous information networks
- Towards foundations of cyber-physical networks