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Automatic inference of clinical workflow events using spatial-temporal tracking

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And many students

Penn State, November 2009

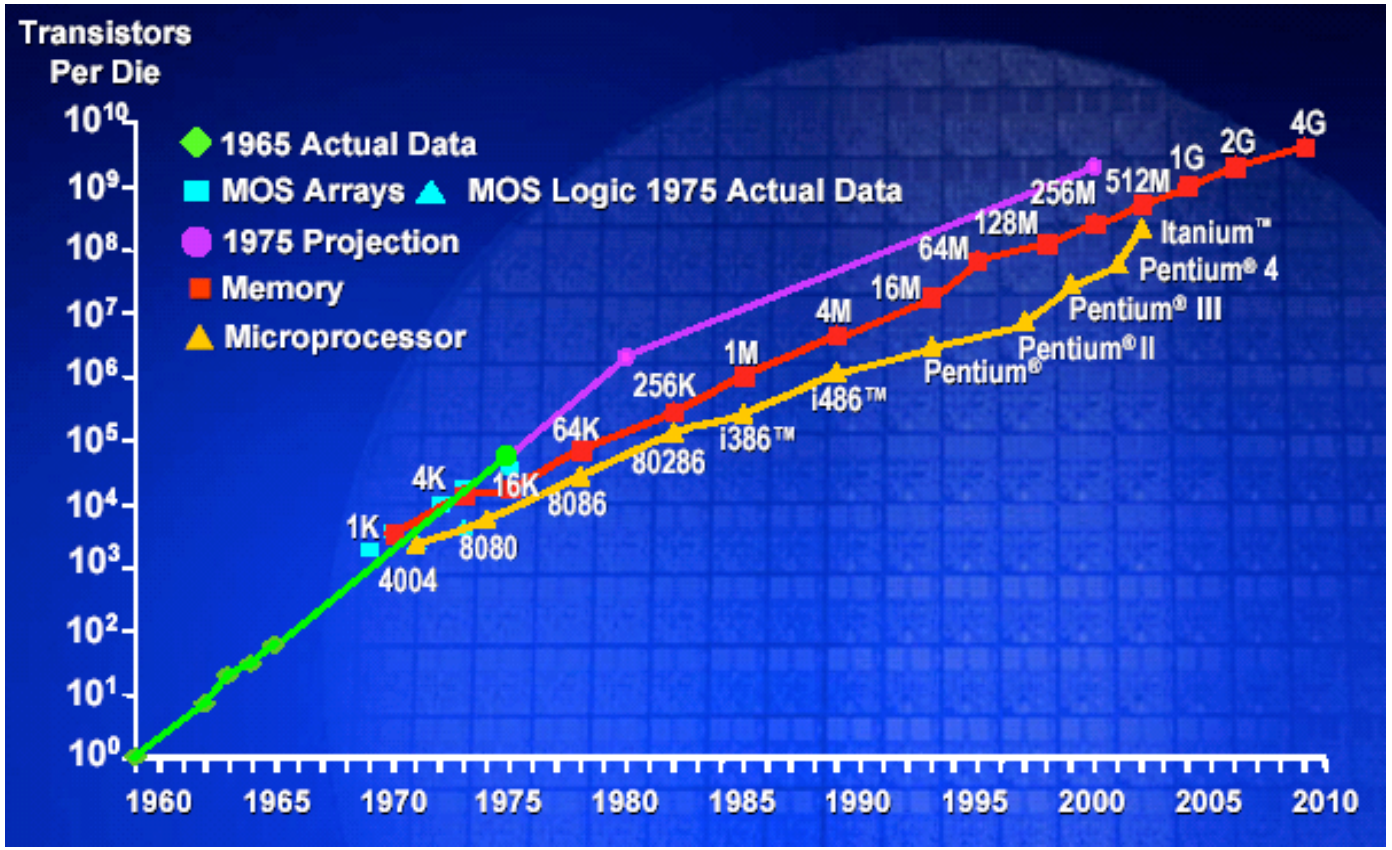
Outline

- Promise of Sensor Networks and Cyber-Physical Systems
- Application Overview:
  - Workflow for an Emergency Department
- Recent Results:
  - Events, Localization and Tracking
  - Workflow
- Open Research Challenges and Future Work

The Promise: A New Application Class

- Observation and control of objects and conditions in physical space
- Driven by technology trends
- Will create a new class of applications
- Will drive existing systems in new ways

IT growth arising from Moore's Law

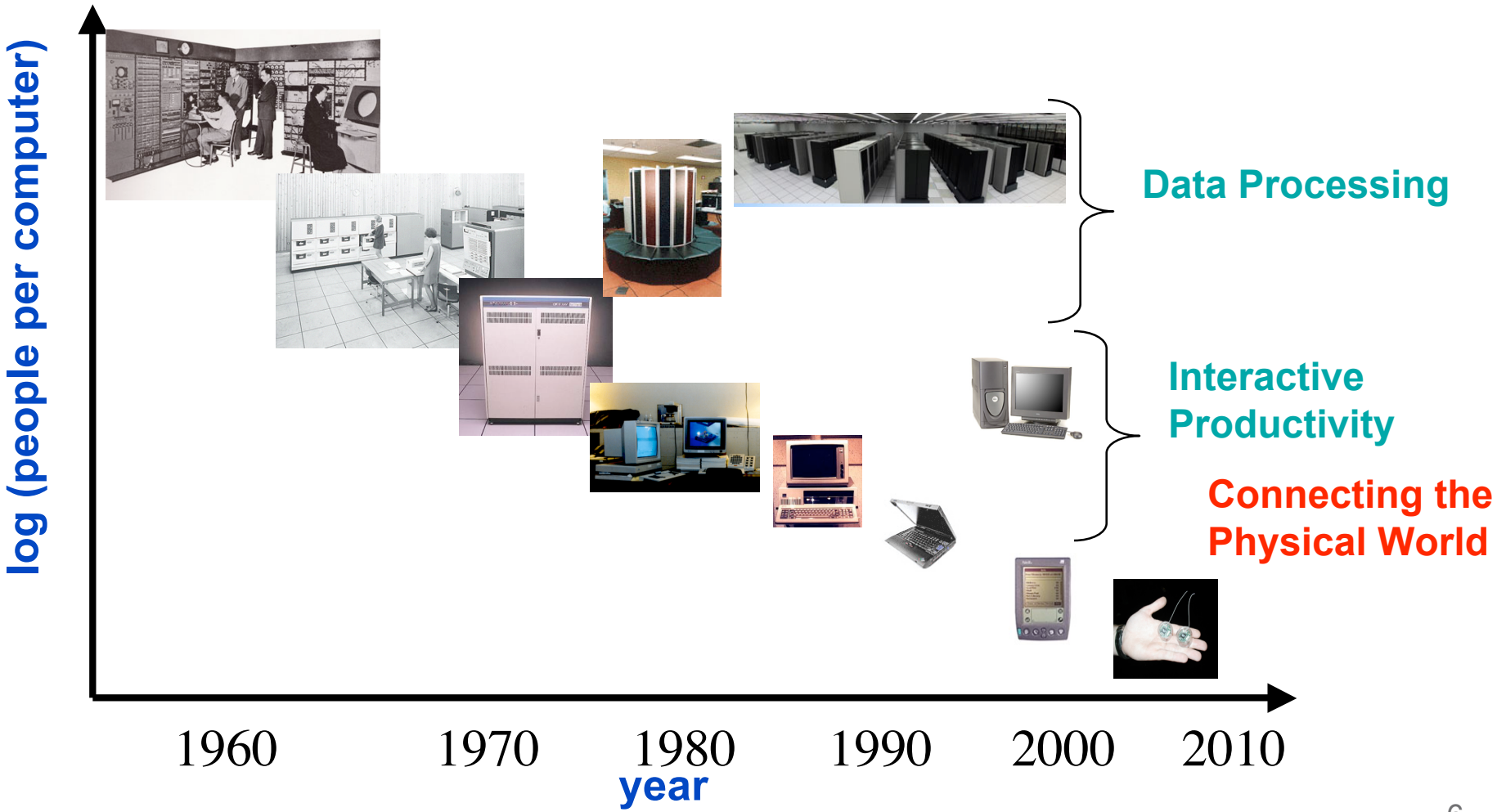


- Law: Transistors per chip doubles every 12-18 months

Impacts of Moore's Law

- Increased power and memory of traditional systems
  - 386,486,Pentium I,II,III
- Corollary: Bell's Law
  - Every 10 years a new:
    - Computing platform
    - Industry around the new platform
  - Driven by cost, power, size reductions due to Moore's law

"Bell's Law"


log (people per computer)
Data Processing
Interactive
Productivity
Connecting the
Physical World
1960
1970
1980
1990
2000
2010
year

Turning the Physical World into Information

- Truly new capabilities
  - Observe time and space
- New uses for existing platforms

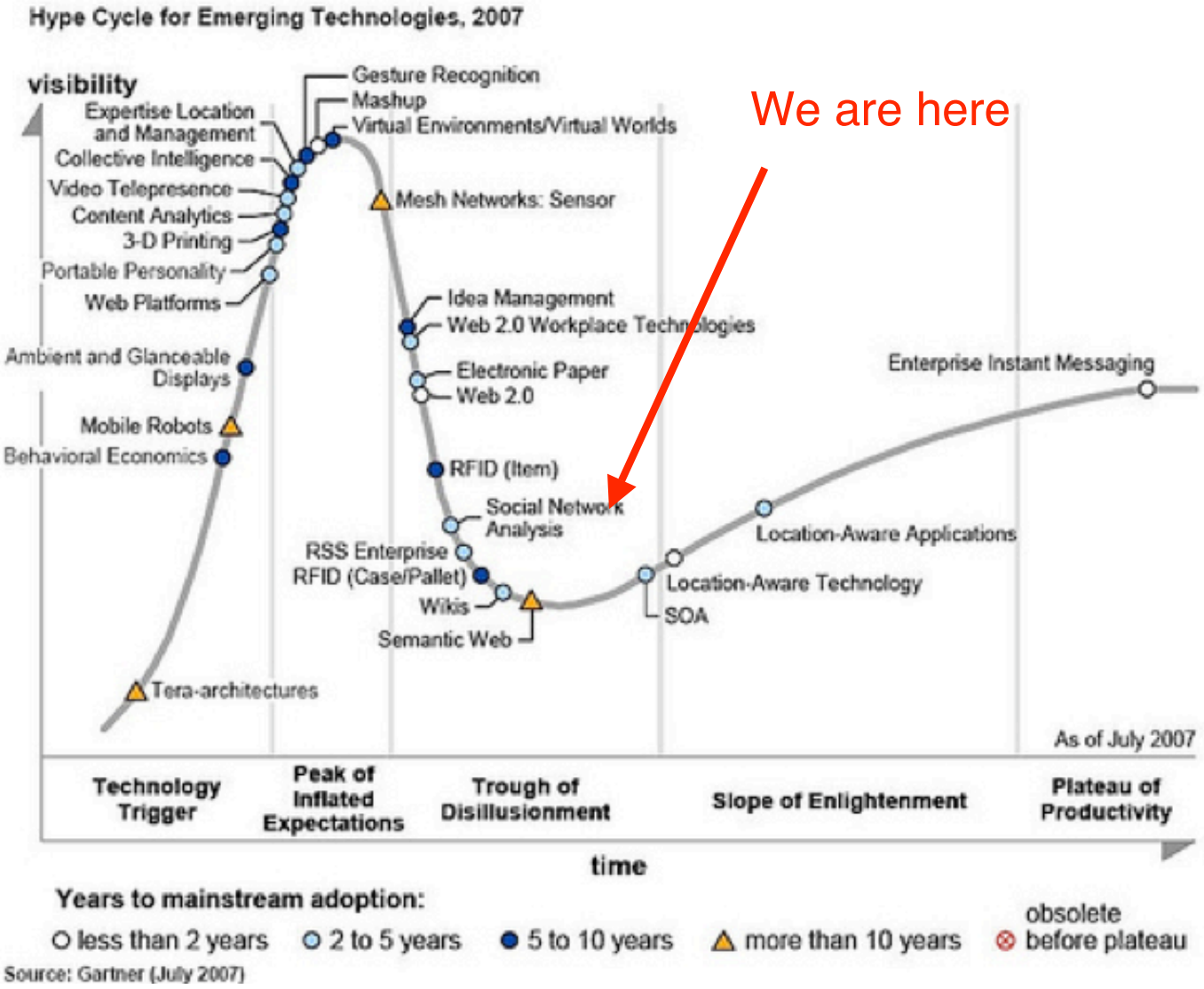
Continuing the trend …

- More transistors will allow wireless communication in every device

- Wireless offers localization (positioning) opportunity in 2D and 3D
  - Opportunity to perform spatial-temporal observations about people and objects

Work over the past 10 years

- 1999: Smart dust project
- 2001: Rene Mote
- 2002-2005:
  - Monitoring applications
    - Petrels, Zebras,Vineyards, Redwoods,Volcanos,Snipers
  - Network protocols: MAC, routing
  - Low energy platforms
  - Languages
  - Operating systems
- 2007-present
  - Integration (IP networks)



WINLAB
WIRELESS INFORMATION NETWORK LABORATORY

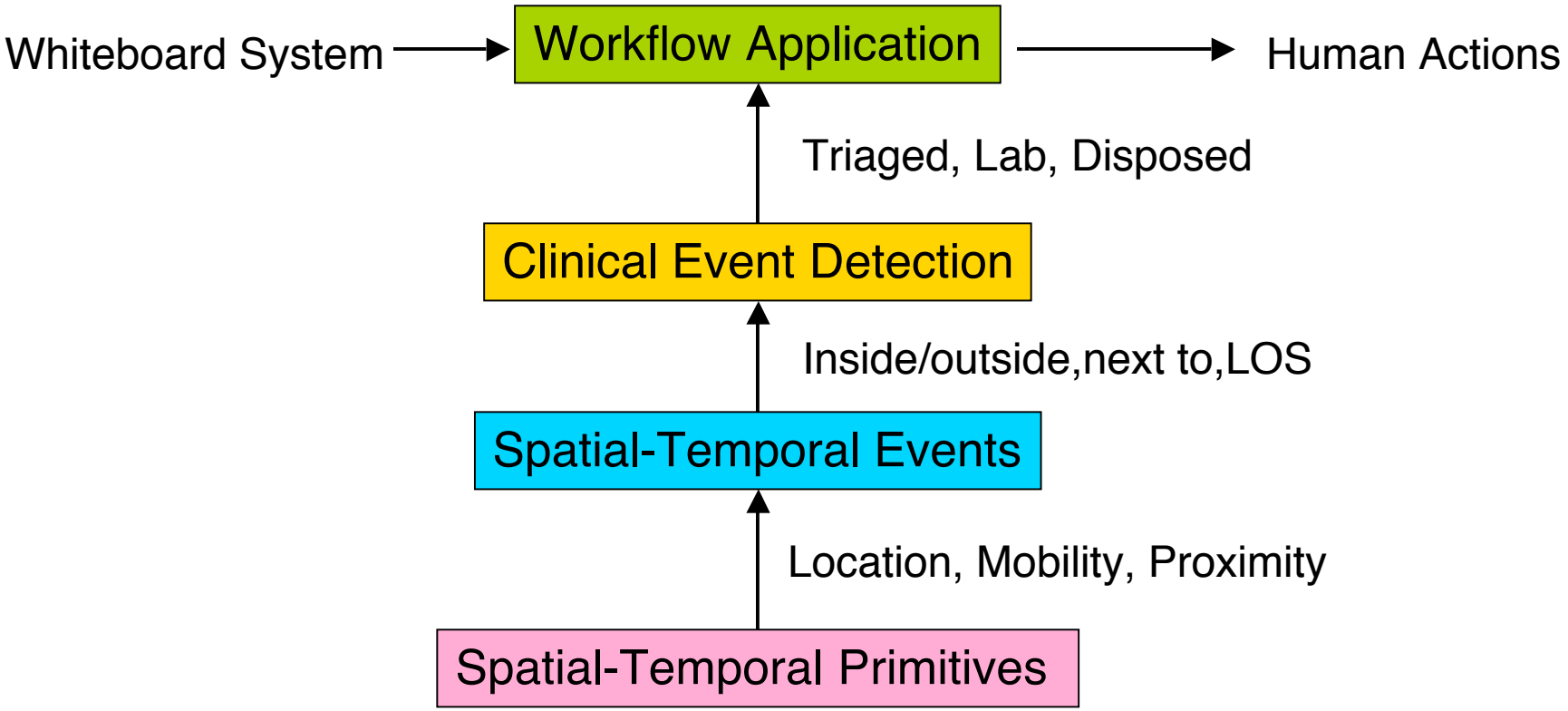
Driving the technology…

- Cyber-physical application past the peak
- Next: vertical app silos to drive the research
    - Analogy: networking in the 1980's
- Rest of this talk: A novel application for workflow management in a hospital emergency department

Healthcare Workflow for an Emergency Department

- Goal: Improve patient throughput
  - Less waiting time for patients
  - Increased revenue for the ED
    - Go from 120 patients/day -> 150/day
- Approach:
  - Automatically deduce clinical events from spatial-temporal primitives of patients, staff, equipment
    - Assume everything has a wireless device
  - Translate clinical events into workflow actions that improve throughput

Software Stack



Spatial-Temporal Primitives

- Location
  - Instantaneous (X,Y) position at time T
- Mobility
  - Moving or stationary at time T
- Proximity
  - When were objects close to each other
- Given sufficient resolution for location, others can be derived
  - Not at a sufficient level of resolution yet.

Spatial Temporal Events

- Enter/Exit areas
- Length of Stay (LOS) in an area
- Transitions between areas
- Movement inside an area
- Sets of objects with the same events in the same areas

Clinical Events

- Greeting
- Triage
- Vitals
- Registration
- Lab Work
- Radiology
- Disposition
- Discharge/Admit

Workflow improvement:

- Treatment is a pipelined process
- Bubbles in the pipeline cause delays
- Dynamically reorganize activity to keep a smooth pipeline:
  - Pull nursing staff from treatment to triage during surge
  - Move physicians between units
  - Have staff push on process delays taking too long
    - Lab, radiology, transport
  - Introduce accountability to change behavior

Current Research

- Roll-Call
  - High density active RFID tags
    - Rich Howard and Yanyong Zhang, Rutgers
- Primitives and Spatial Events:
  - GRAIL
  - Localization
  - Mobility Detection

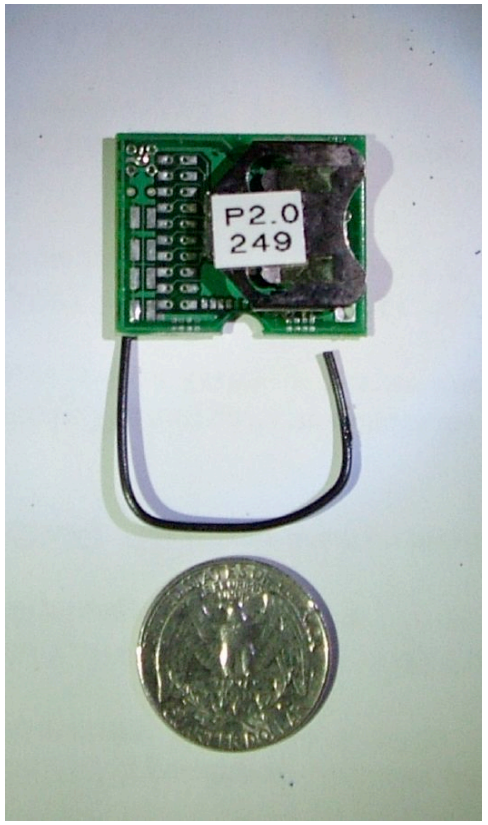
Roll-Call

- Goal: High density, low cost active RFID tags + readers
- 1,500 tags/reader possible with 1 second beacon rate (simulated)
  - 100 + actual, (not enough tags!)

Roll-Call Active RFID Tags

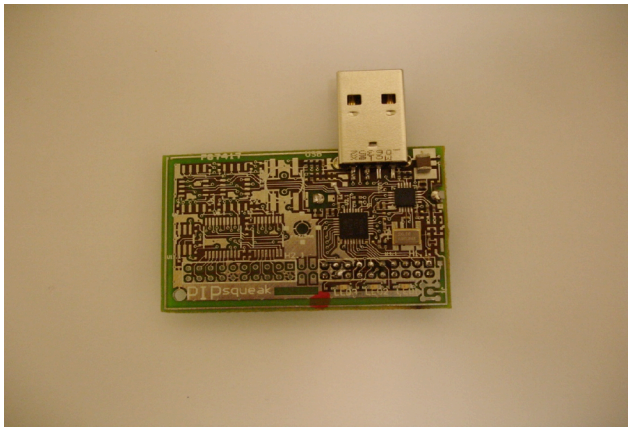
- Pipsqueak RFID tags from InPoint Systems (Rutgers WINLAB spin off)

- Version2:
  - 1 year battery lifetime @ 1sec
  - $30/each in (quantity 100)
  - $20/each (quantity 1000)
- Version 3:
  - 4 year battery life @ 1sec
  - $20 each (quantity 100)



Roll-Call Reader

- Low cost readers
  - USB “key”
- Allow widespread deployment
  - Every desktop => reader
- Allows low-power readers
  - inside shipping container



Research Challenges

- Transmit-only protocols
  - Compare to 2-way communication
- Group-level time-domain scheduling
  - Read/listen tags
  - Low energy read environments
- Energy management
  - Tag-level
  - Global/Area

GRAIL: Motivation

- Maintains real time position of everything
  - Plausible:
    - $2 active tag (including battery) ($20-30 today)
    - $0.25 passive tags ($0.5 - $4 today)
- Use in Cyber-Physical applications

GRAIL opportunity and vision

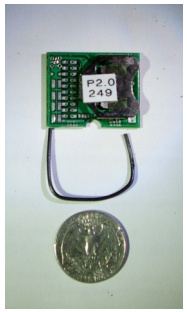
- General purpose localization analogous to general purpose communication.
  - Support any wireless device with little/no modification
  - Supports vast range of performance
    - Devices: Passive tag/Active Tag/Zigbee/Phone/Laptop
    - Scales: City/campus/building/floor/room/shelf/drawer
  - Localize in any environment the device could be in
  - Only return device position to the people of concern (privacy, security features)
    - Permissions, Butlers, Anonymized IDs, Expirations

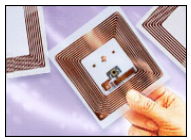
GRAIL Project

"We reject: kings, presidents, and voting.
We believe in: rough consensus and running code"
-David Clark, IETF meeting, July 1992

- Open source infrastructure for localization
  - http://grailrtls.sourceforge.net
  - Need to move community beyond algorithms
- Allows independent progress on different fronts:
  - Physical layers, algorithms, services
- Used by Rutgers, Stevens, Lafayette

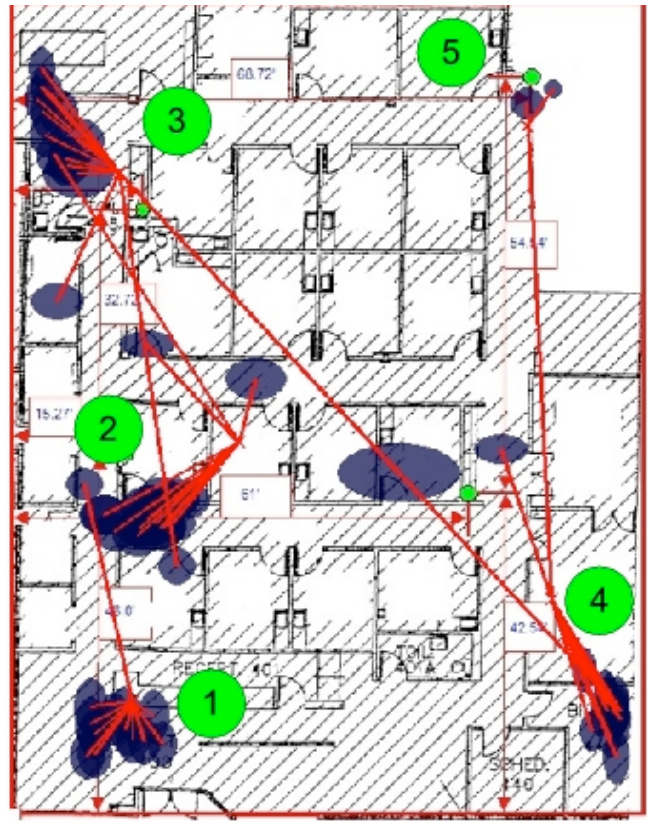
GRAIL System Model





Example PDA/WiFi Tracking

1. Reception
2. Nurses Room
3. Examination Room
4. Physician Room
5. Side Desk



: Localized estimate (+/- 1σ)

X : Ground truth

: Landmark

Tracking Demo

http://www.screentoaster.com/watch/stV0pWSkBIR1xYR1VVUltcV1FW

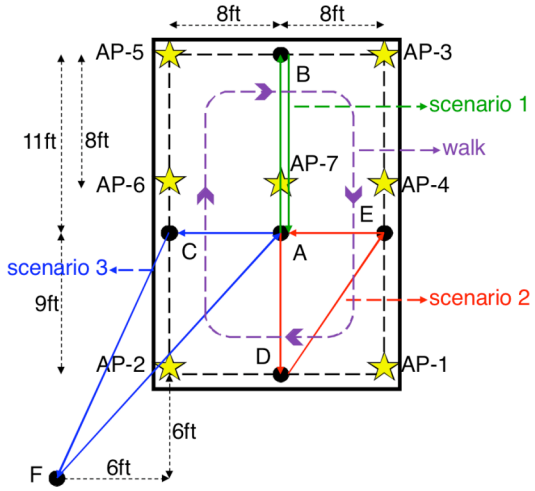
Technical Lessons

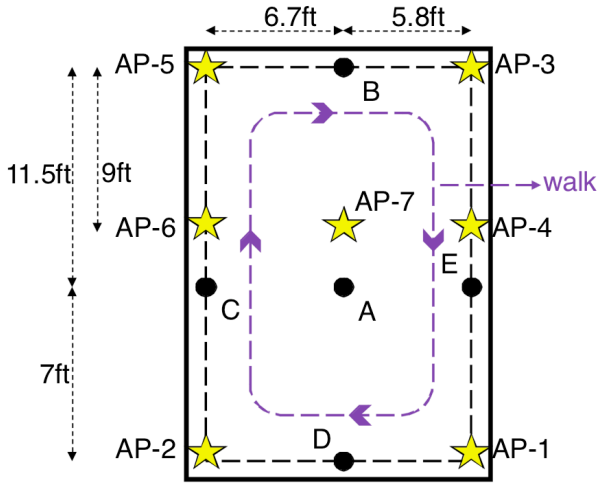
- Expect 10-15 ft. accuracy
  - Probably OK for most applications
- Pipsqueak RFID tags as good a WiFi
  - Requires slightly denser deployment
- Good antenna exposure critical
  - Must hide tags and expose antenna too
- Can we mix an array of technologies?
  - Passive tags, bluetooth phones?

Mobility Detection

- Detect if a device is moving or is stationary
- Approach:
  - Record Received Signal Strength over Time Window
  - Compare histograms of RSS using:
    - Mean
    - Variance
    - Earth Mover's Distance (EMD)
  - Threshold detection
    - Threshold found using 9 fold x validation and RIPPER alg on 1 room

Room scenarios





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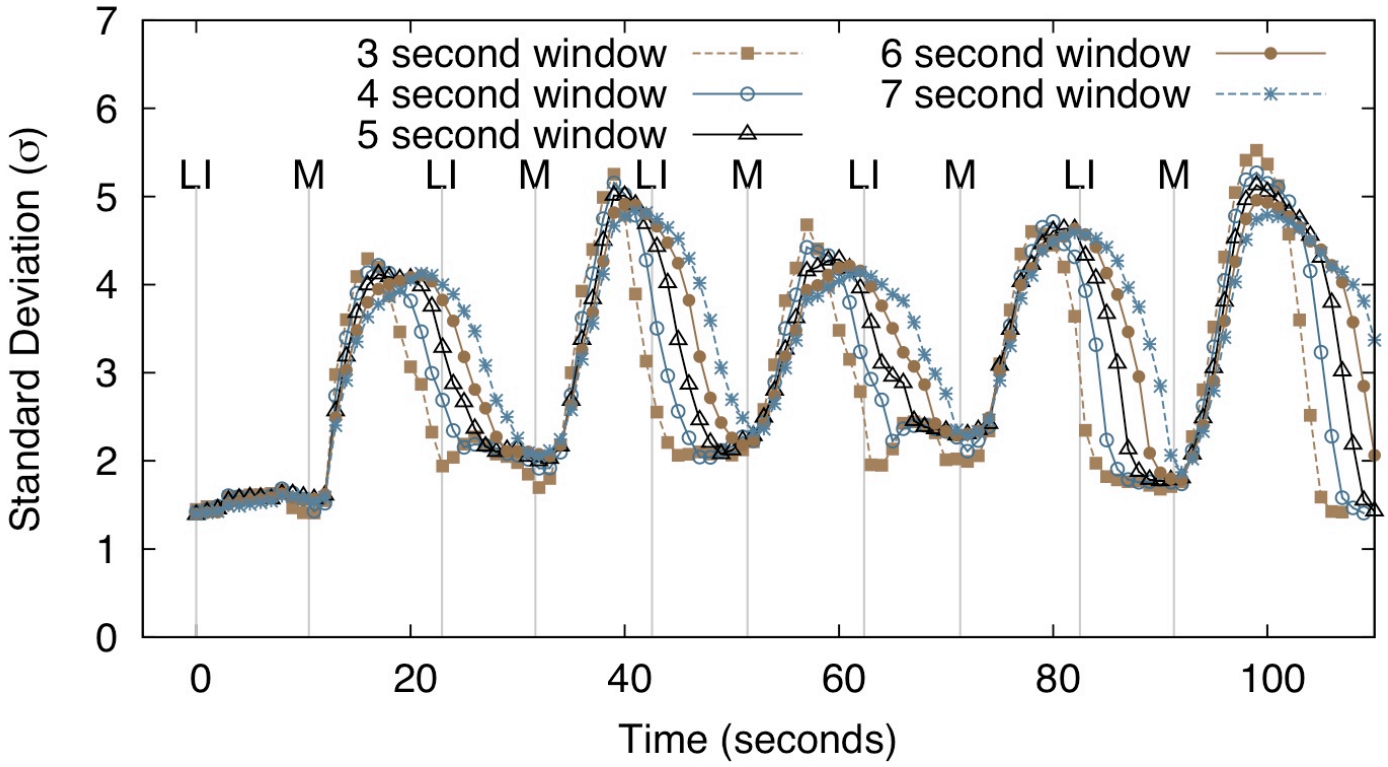
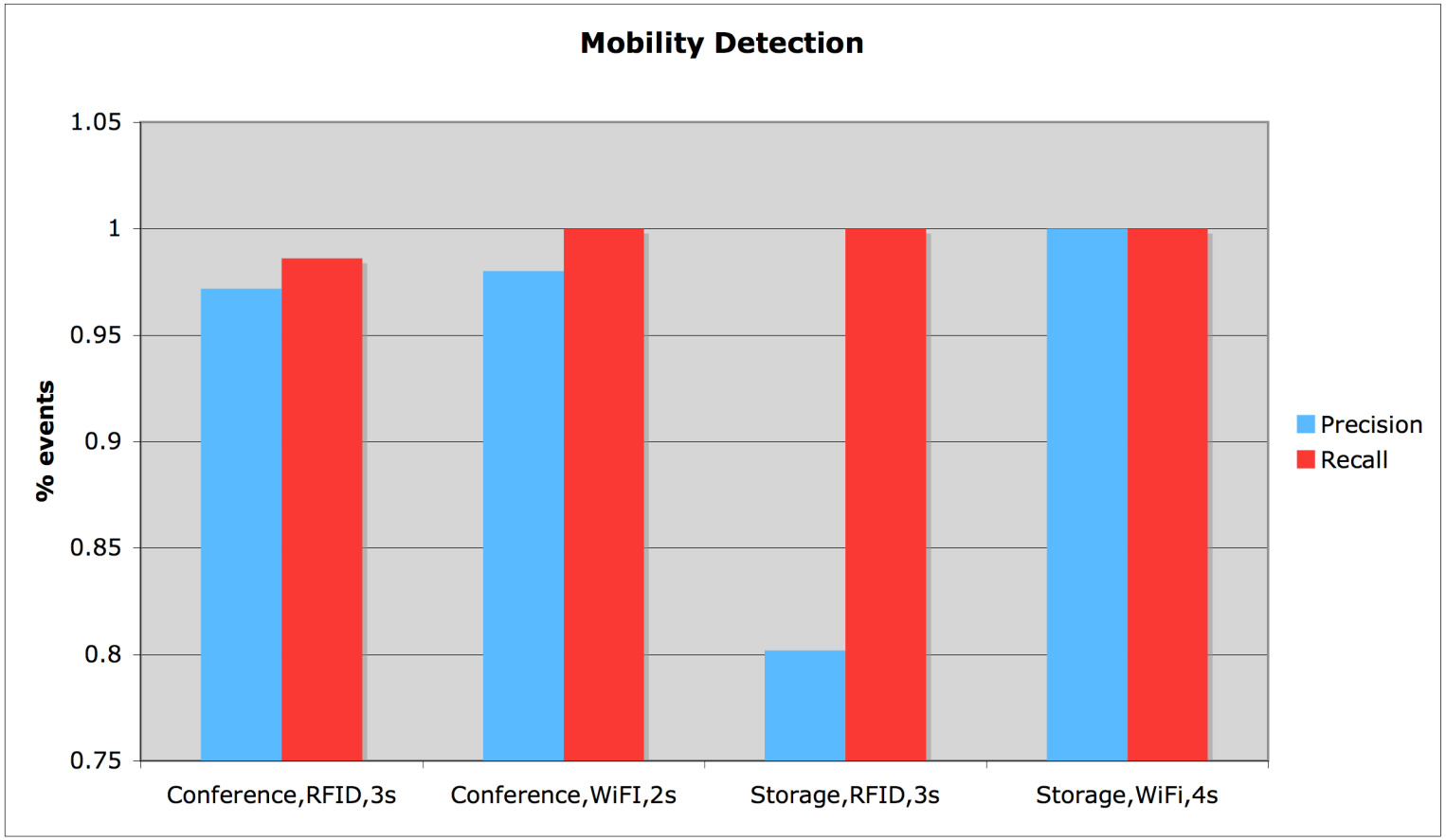
Example RSSI Trace



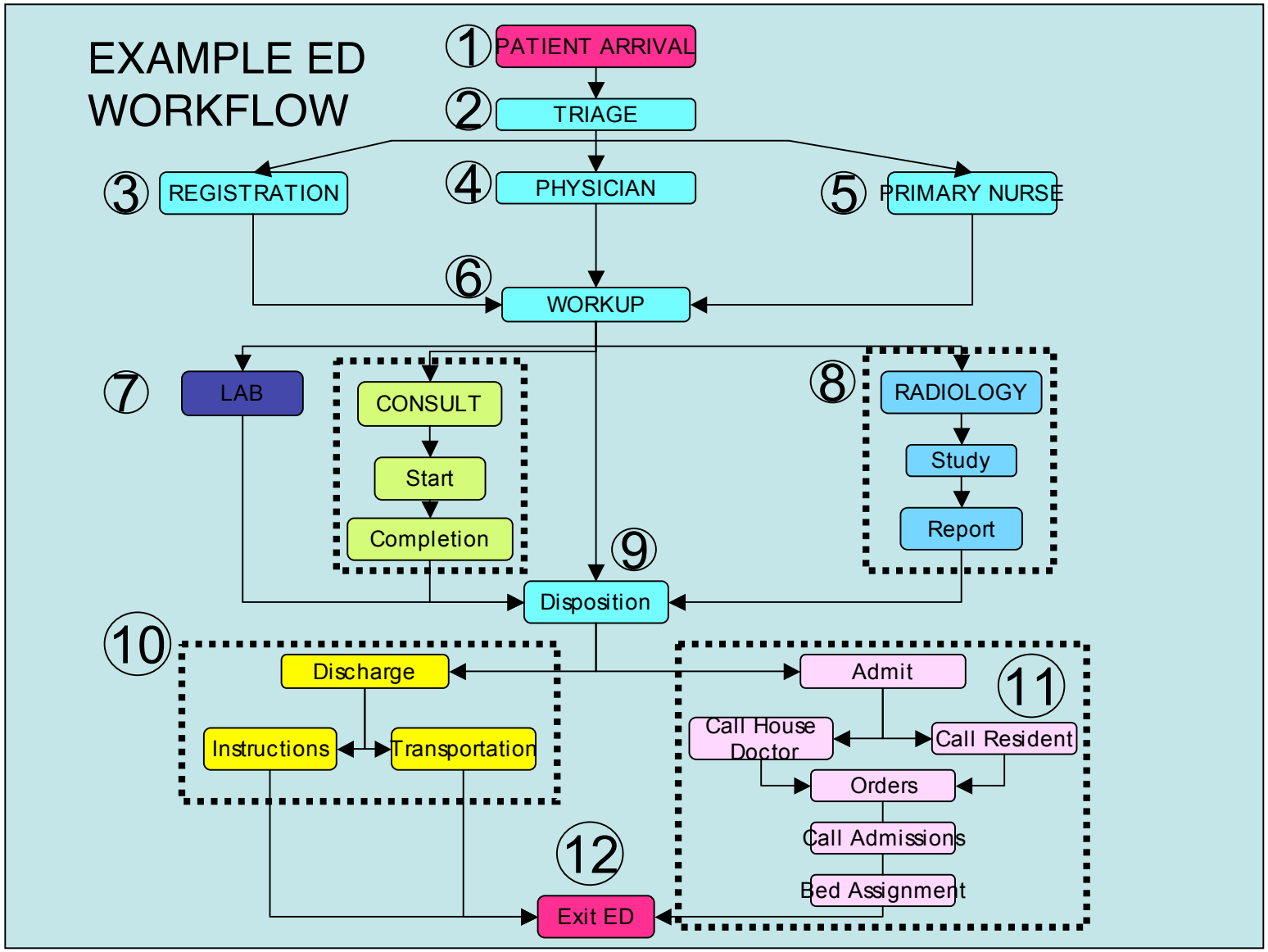
LI=Local Movement M=Laptop Moved

Detection Results



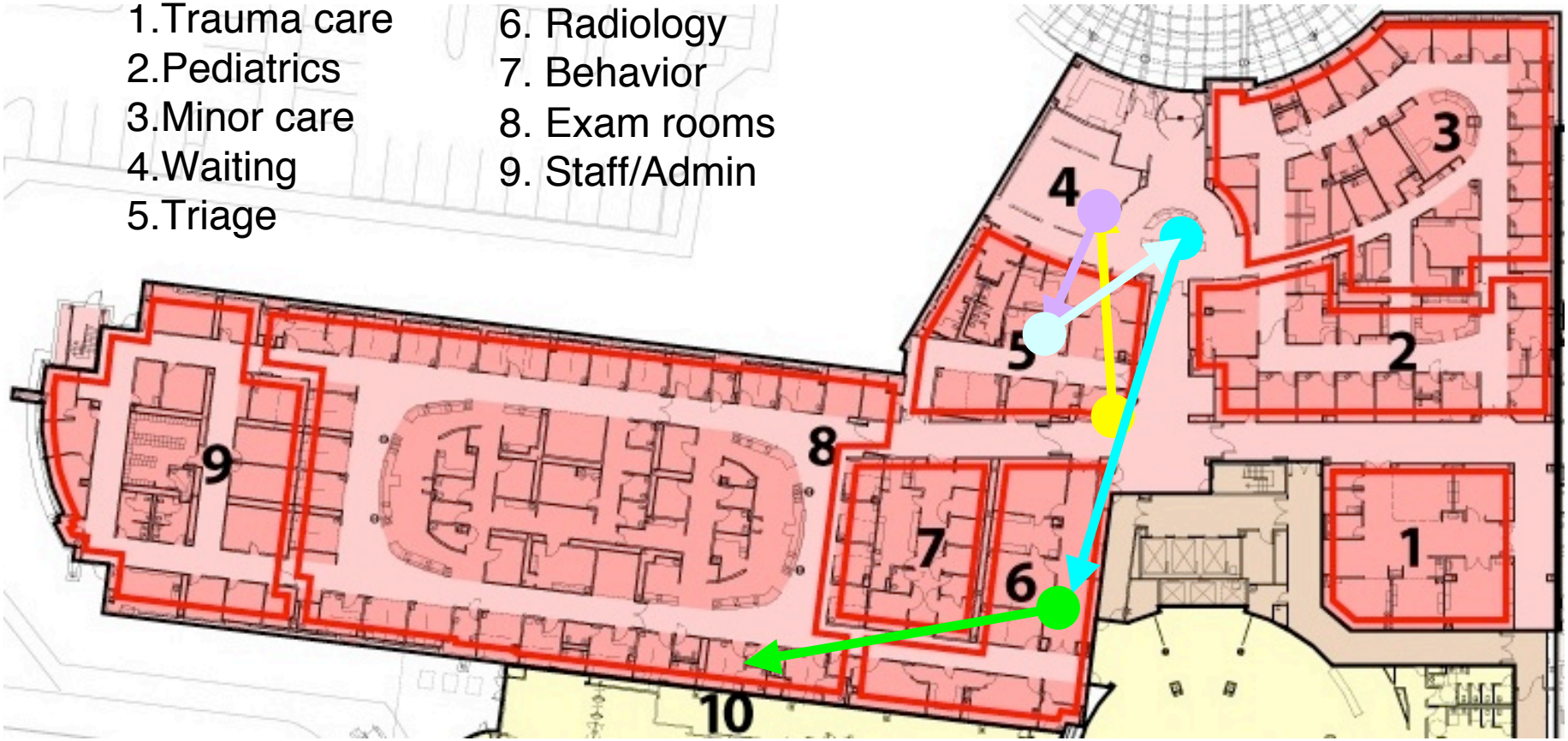
Clinical Event Detection

- Rule sets for mapping Spatial-Temporal primitives and events to clinical events
- Map XY primitives to room (areas) event
  - Enter/leave, Length of Stay (LOS)
- Room-level sequences + equipment mobility-> clinical events
  - Use streaming database abstractions (e.g. esper)


EXAMPLE ED WORKFLOW
1
PATIENT ARRIVAL
2
TRIAGE
3
REGISTRATION
4
PHYSICIAN
5
PRIMARY NURSE
6
WORKUP
7
LAB
CONSULT
Start
Completion
8
RADIOLOGY
Study
Report
9
Disposition
10
Discharge
Instructions
Transportation
11
Admit
Call House Doctor
Call Resident
Orders
Call Admissions
Bed Assignment
12
Exit ED

Example events

1.Trauma care
2.Pediatrics
3.Minor care
4.Waiting
5.Triage
6. Radiology
7. Behavior
8. Exam rooms
9. Staff/Admin



Integration with Workflow

- Build events into exiting workflow system (YAWL)
- Assign new tasks
  - Change areas/roles (treatment->triage)
  - Call/inquire about length of time:
    - Labs, radiology, transport
- Reorder tasks
  - Prioritize patients waiting the longest
- Re-organize space?

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Research Challenges

- Integration with the Internet
  - Global Network Infrastructure sees all traffic, but routes data. Were to include position?
- Privacy and security controls
  - Manage area vs. device owners
- Positioning robustness
  - Bound maximum positioning error

Conclusions

- Time for focused application drive
  - What's really important vs. what we thought was important
- Will require a lot thinking about software stacks
  - Lower layers, events,

Thank you!