Targets and Shapes Tracking

Advanced Seminar

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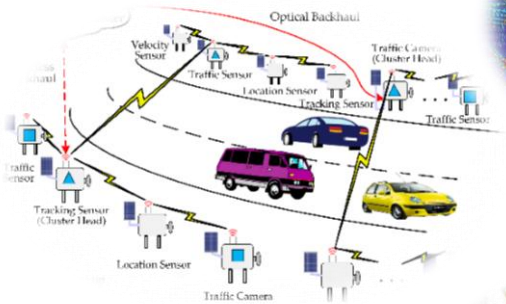
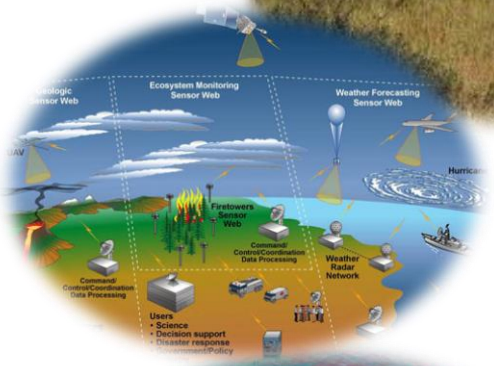
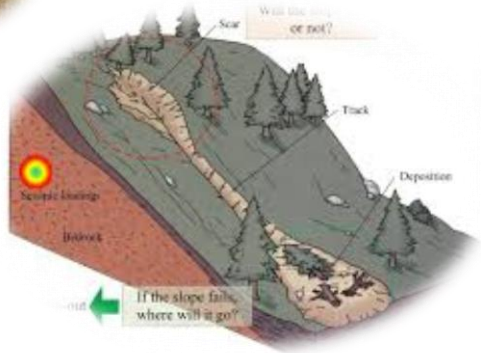
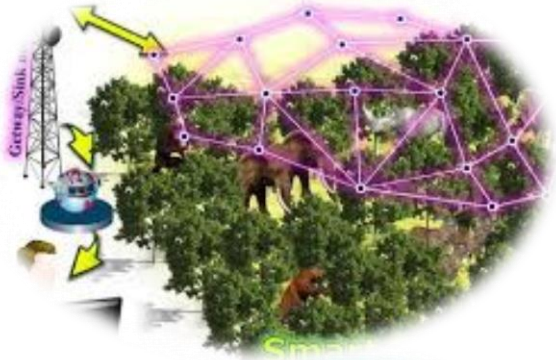
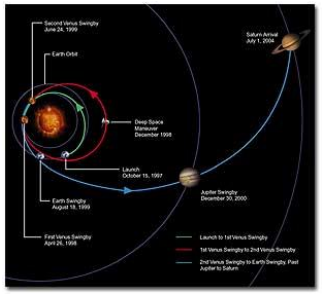
Tracking… Plethora of Application Domains











Tracking… Global Perspective

- Process

involving:

Devices capable of sensing particular phenomena

Sensors:
Vibration, Acoustic, Temperature, Humidity, Acceleration, Images, Location, Heart rate, Salinity, CO2…

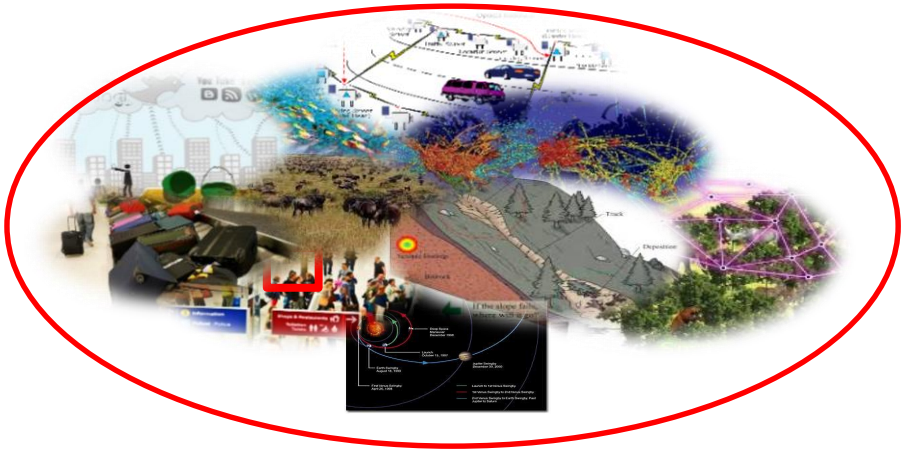
Constraints on sensors:

GPS: imprecision; does not work indoors
Roadside Sensors: cannot distinguish lanes
Cameras: Cannot be place enough-many (not cheap)
RFID: non-flexible (cheap tags, but readers location)
…
…

Devices capable of communication

Constraints:
WSN: energy depletion
VANET: proximity; freshness
Participatory Sensing: privacy; coverage
Indoor: scattering…
…

Tracking… Global Perspective



- Process

involving:

Devices capable of sensing particular phenomena

Devices capable of communication

Processing Environments and Algorithms:

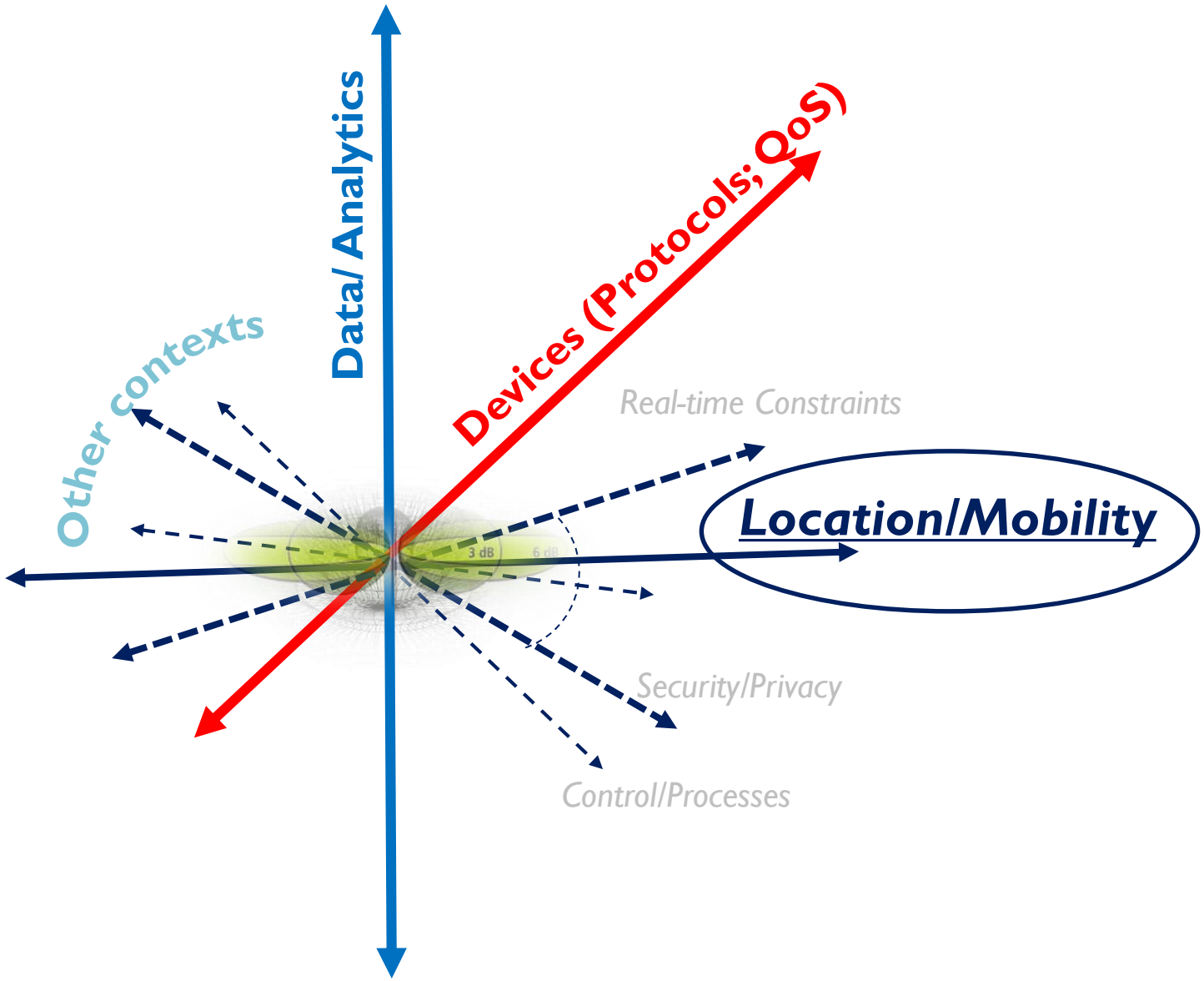
Distributed (in-network)
Centralized
…

With a purpose of:

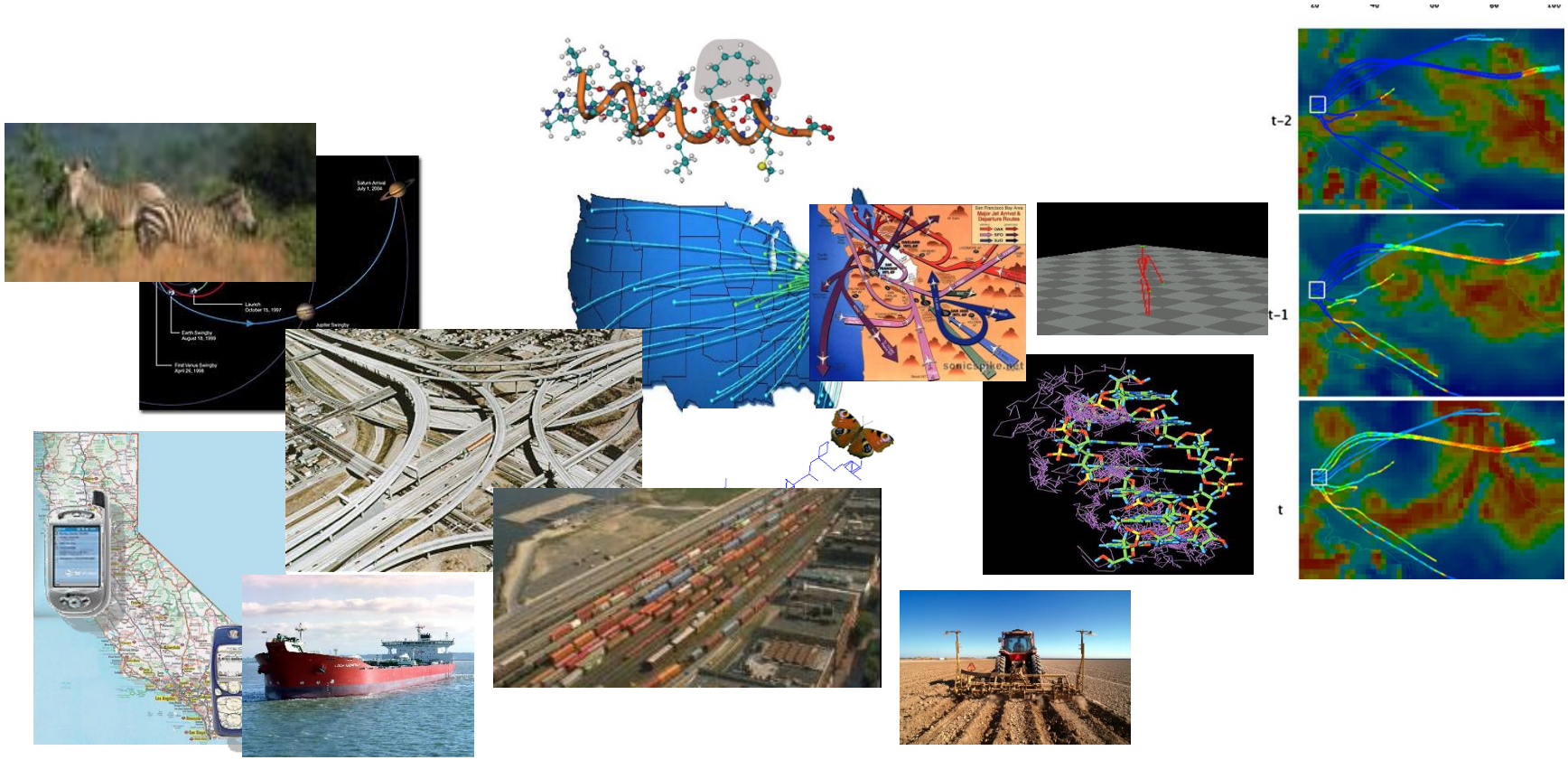
Detecting occurrence of event or predicate (composite event)
Constructing notifications (and other actuations)
Maintaining answers to (continuous) queries
…

and, with Constraints… (syntax, processing,…)

Tracking – Meta Perspective



Tracking and Mobile Data… Seminar Context



Mostly, impact of location (+ time);
Impact(s) of detection(s);
Global Settings:

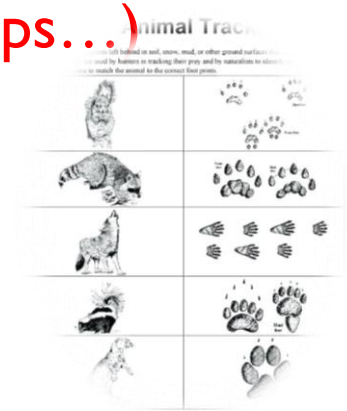
- Location Based Services
- Data Fusion
- Social Networks
- …

Outline

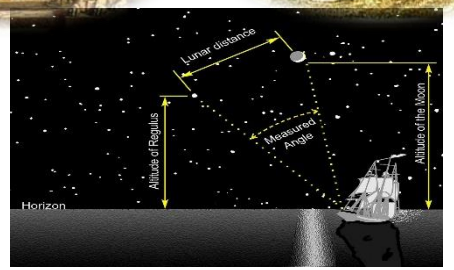
- History
  - Ancient
  - Less Ancient
- Moving Objects Tracking
  - Road Networks
  - WSN
- Queries/Predicates
  - Shapes Tracking
  - Applications' domains and properties
- Tracking Boundaries and Topologies
- Tracking and Social Networks
- Influence and Diffusion Tracking

History – Ancient Times

- Historically, the first "organized"/recognized tracking was in the domain of hunting
  - Still popular today (apps…)



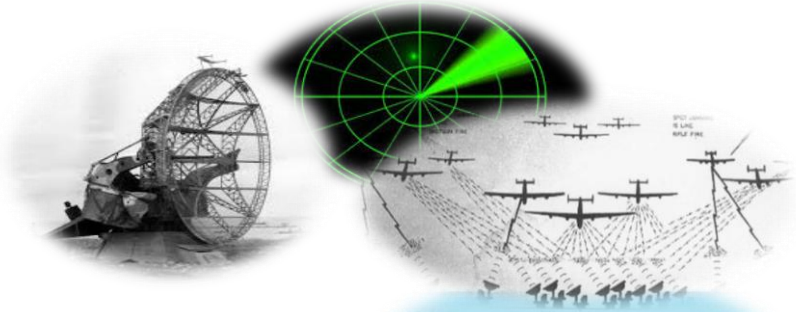
- Similarly – warfare…
- Less commonly acknowledged in the past centuries, but much more so in the more recent past:
  - Tracking of celestial bodies
  - Correlation with earthly tasks/processes
    - Seasons; Planning (harvest)
    - Navigation

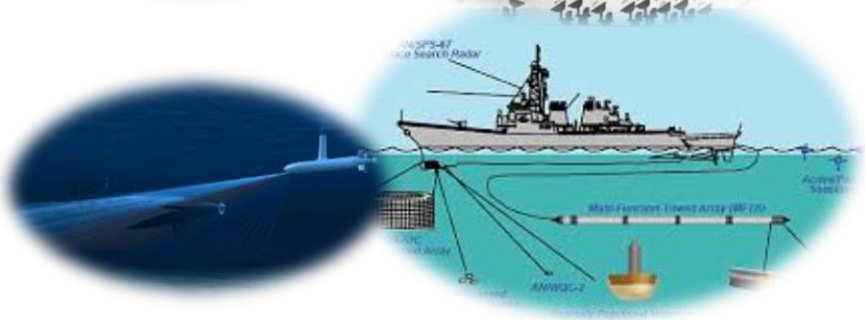


History – Less Ancient Times (FF)

- Tracking (…not exactly mobile…) data:
  - Census
  - Stock market

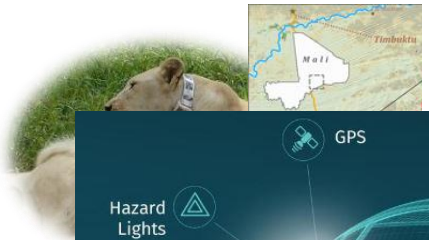
- WW II:
  - Radars – issues:
    - Representation
    - Coverage
  - Sonars (relative positioning)

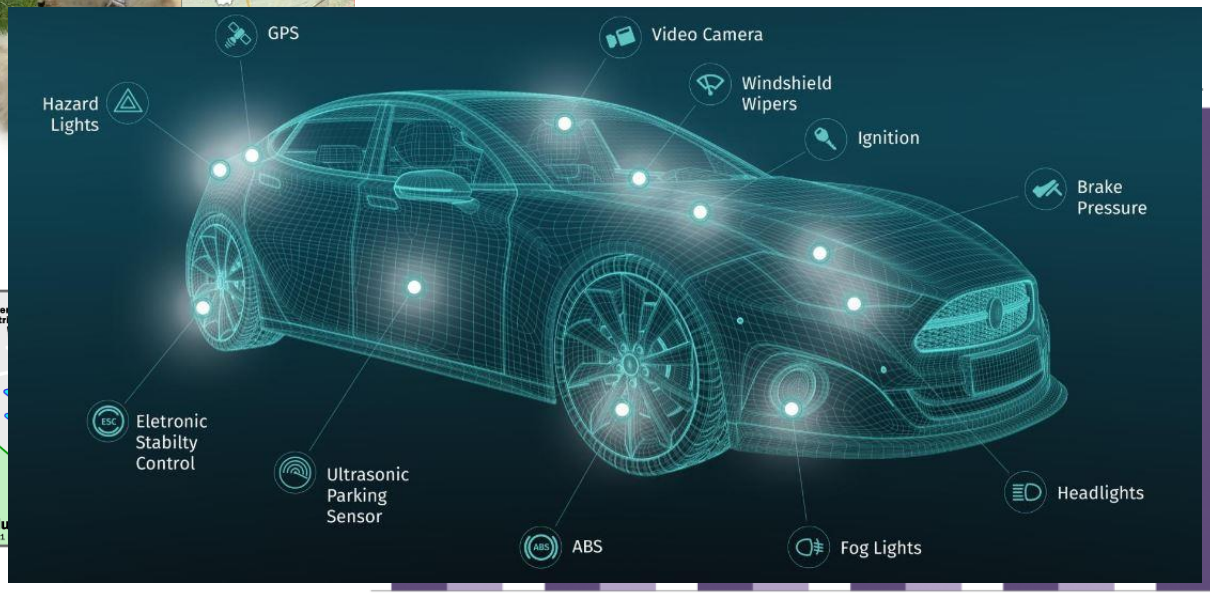


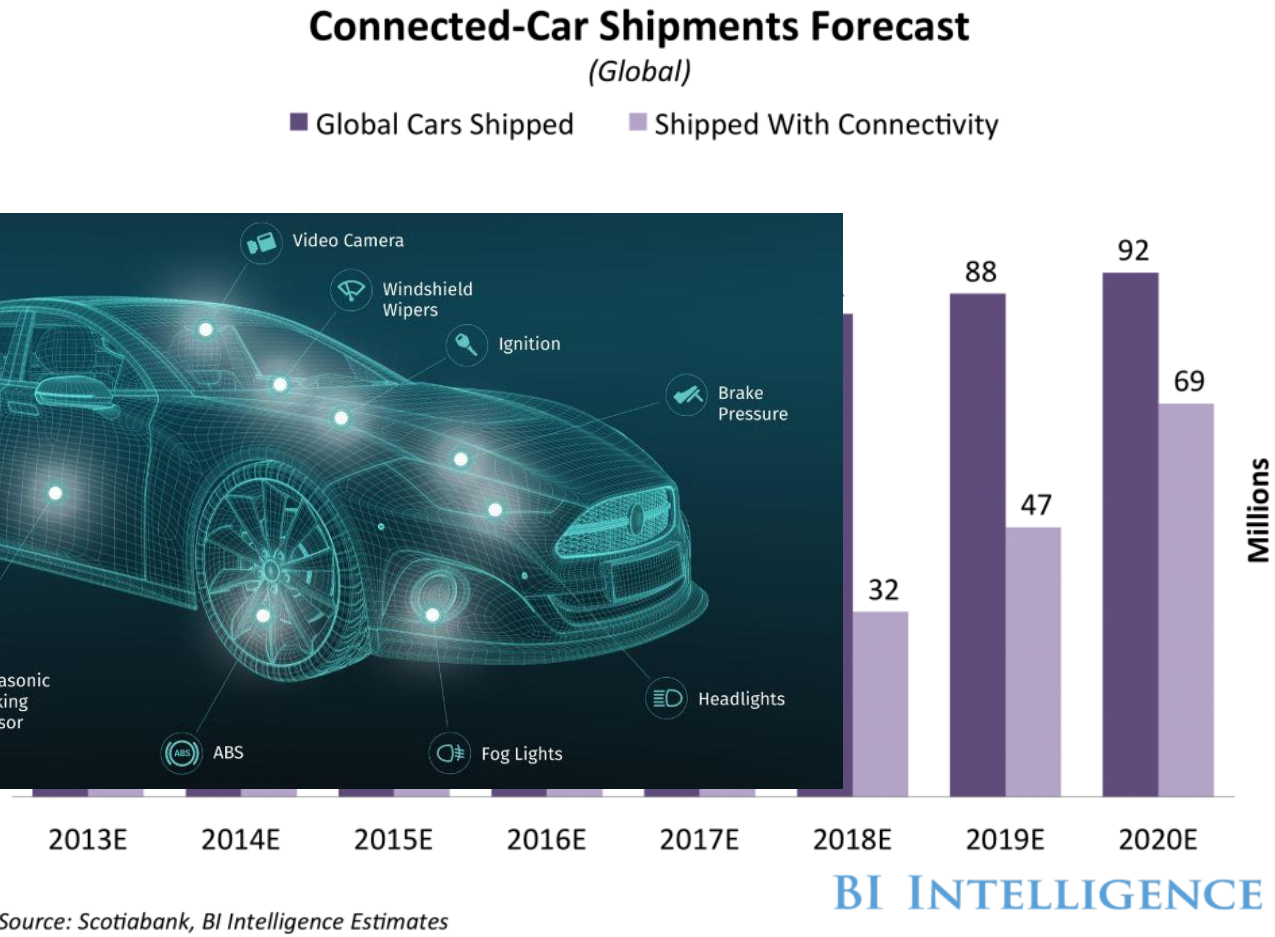


- Tracking
  - Ships/Trains
  - Goods/People

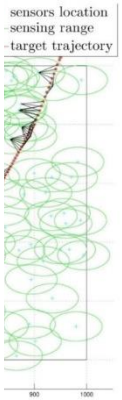
- Generation of data:
  - GPS; Sensors; Inductive Loops; Probe-cars;
  - Smart phones







Source: Scotiabank, BI Intelligence Estimates



"Net"-effects:

O(PB) from GPS data (x 400 for cellular-based)

Tens/Hundreds of Sensors, generating ~20GB daily (not counting apps…)

- Moving Object

Changes its spatial whereabouts over time (during its existence)

Any real-world element that may be perceived as "unique" (a car, a person)

Trajectory: continuous mapping from Time to (some Geographical) 2D Space

$$I(\subseteq)\ \mathcal{R} \rightarrow \mathcal{R}^2$$

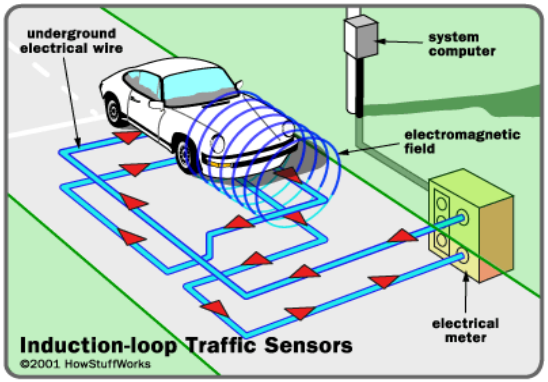
or, parameterization over time: $\alpha(t) = (\alpha_x(t), \alpha_y(t))$

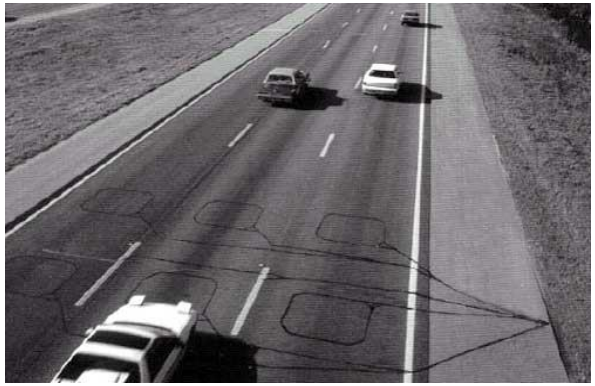
Trajectory = $\{(\alpha_x(t), \alpha_y(t), t) \mid t \in I\}$

- Description
- Representation
- Manipulations (Querying)

Objects may have (spatial) extent – mobile shapes/volumes…

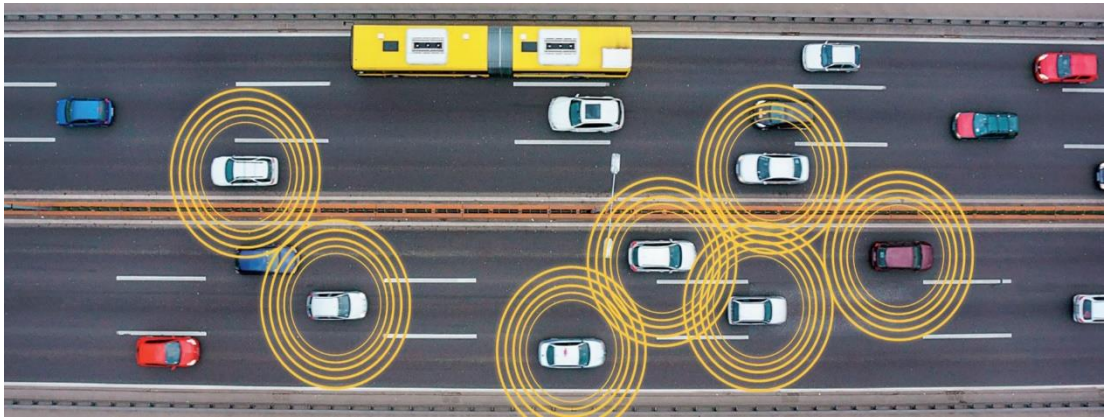
Tracking Moving Objects

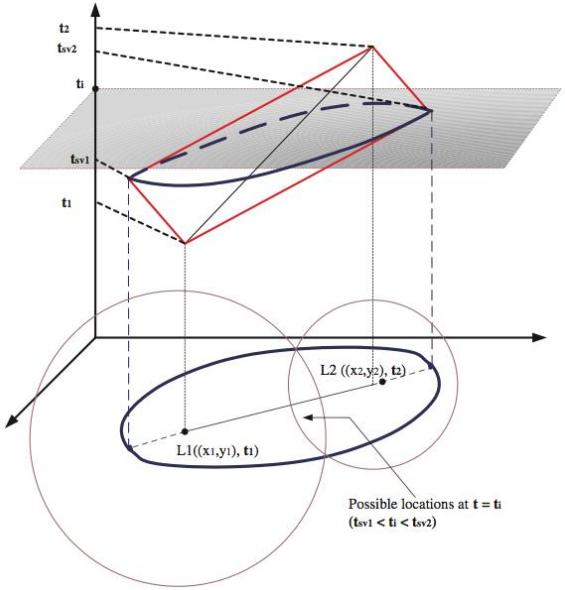




Inductive loop sensor

Cars equipped with internet access (stream music, be alerted of traffic and weather conditions, driving-assistance services…)

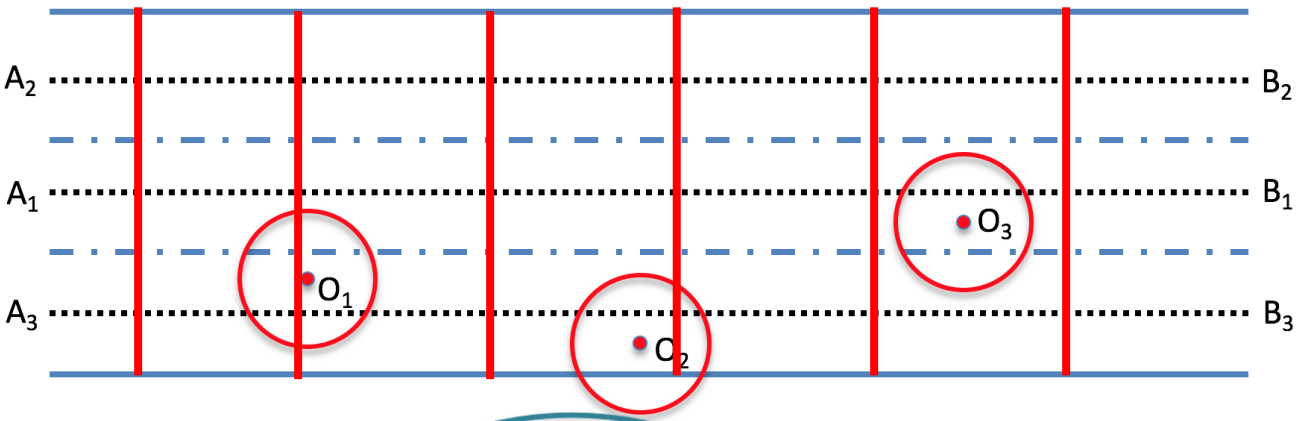


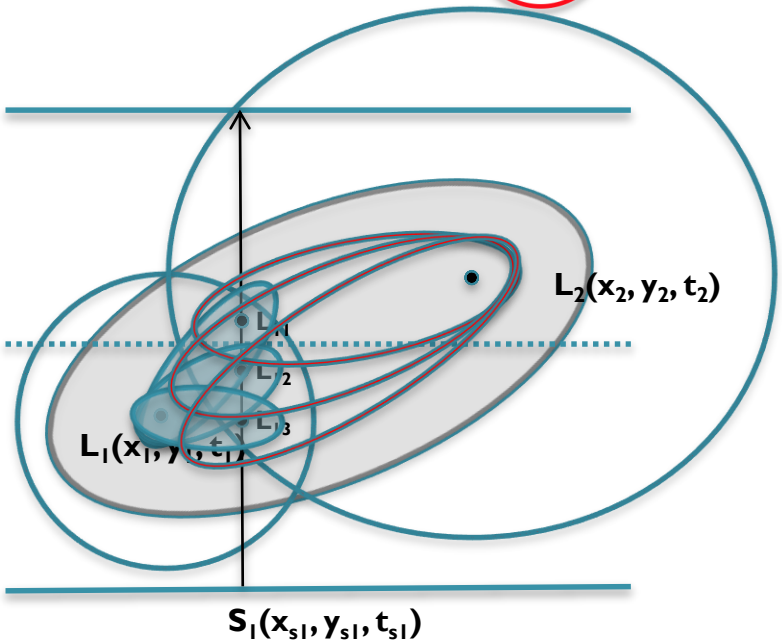


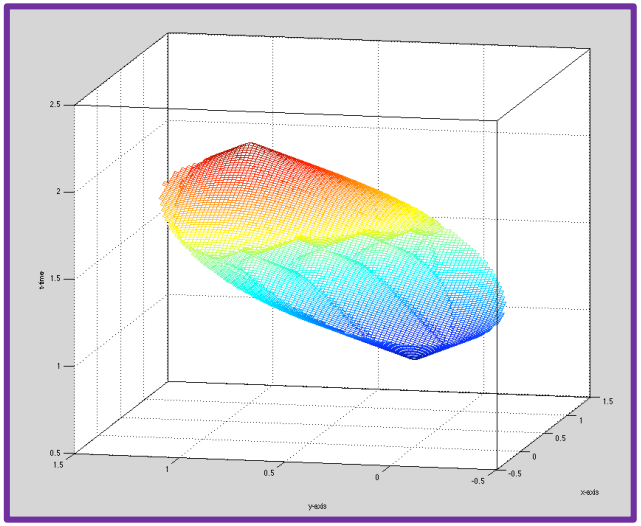
GPS location data

$$\begin{cases} t_i \leq t \leq t_{i+1} \\ (x - x_i)^2 + (y - y_i)^2 \leq [(t - t_i)v^i_{max}]^2 \\ (x - x_{i+1})^2 + (y - y_{i+1})^2 \leq [(t_{i+1} - t)v^i_{max}]^2 \end{cases}$$

- So, two sources…







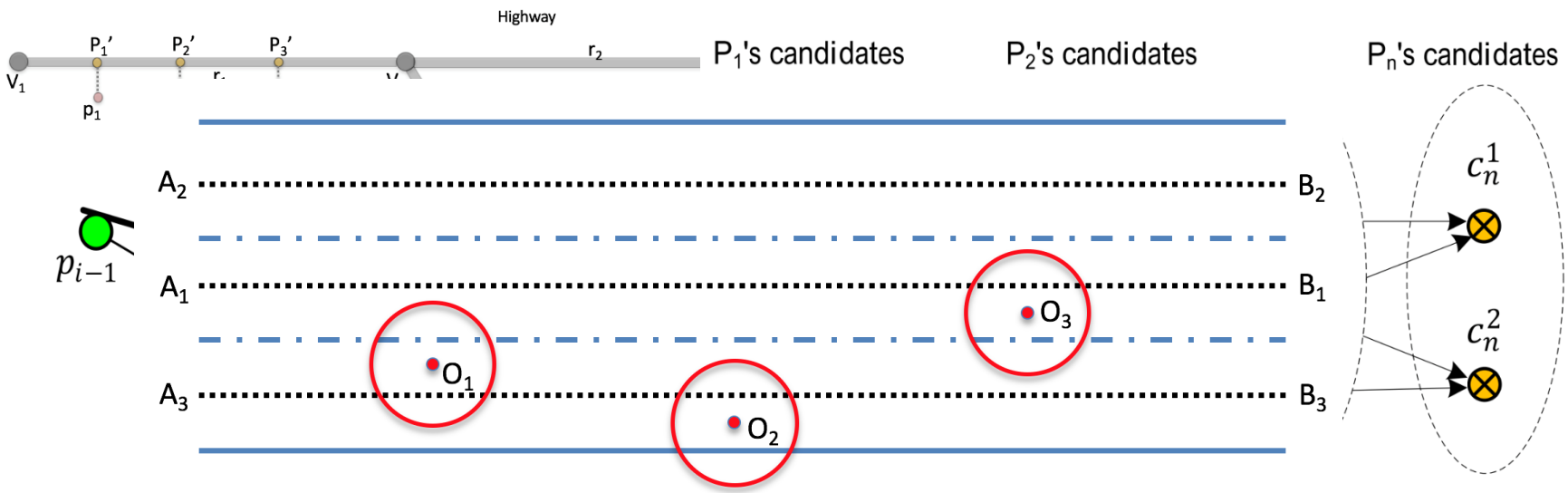
Tracking – Data Fusion and Lane Awareness

On Lake Shore Drive, Cars back up at the rightmost lane by Belmont Avenue exit.

Different lanes on the same road-segment may have significantly different speeds.

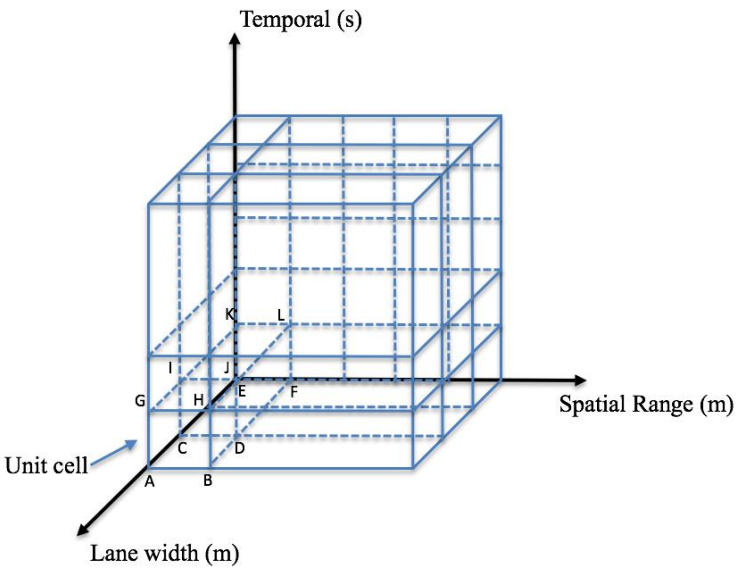
- Solution:

1. Augment map-matching with lane awareness;
2. Generate Unit Cell (UC) for each lane;
3. Cluster "acceptably close" UC



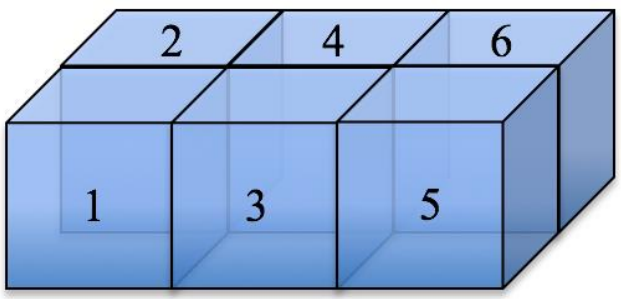
$$P_{lane} = \frac{D_p(x, y, t, r) \cap A}{D_p(x, y, t, r)}$$

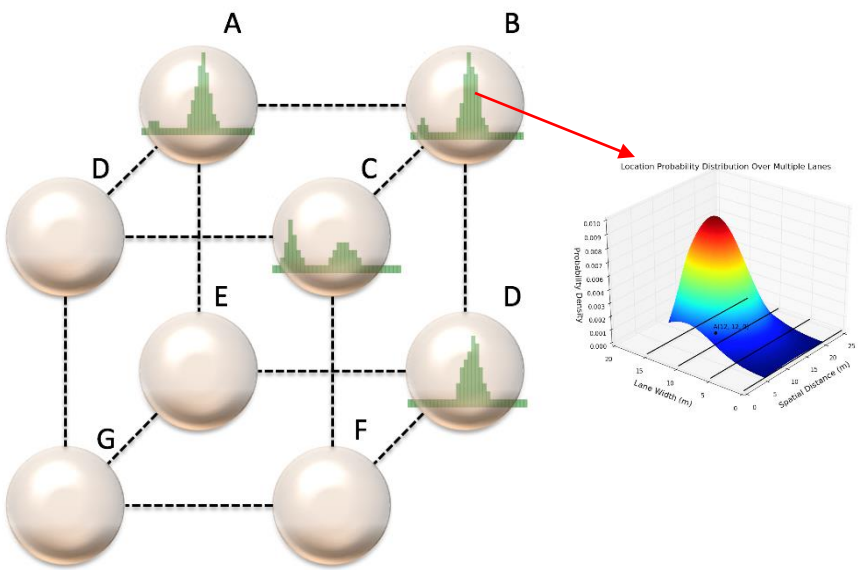
Tracking, Lane Awareness ⇒ Improved Routing/Navigation



1. Augment map-matching with lane awareness;
2. Generate Unit Cell (UC) for each lane;
3. Cluster "acceptably close" UC

- spatial range $\Delta^S_{kl} = d^+_{kl} - d^-_{kl}$
- temporal interval $\Delta^T_{kl} = t^+_{kl} - t^-_{kl}$
- set of trajectories $D_{kl} = [Tr_1, Tr_2, \ldots Tr_n]$
  the GPS points of which belong to it

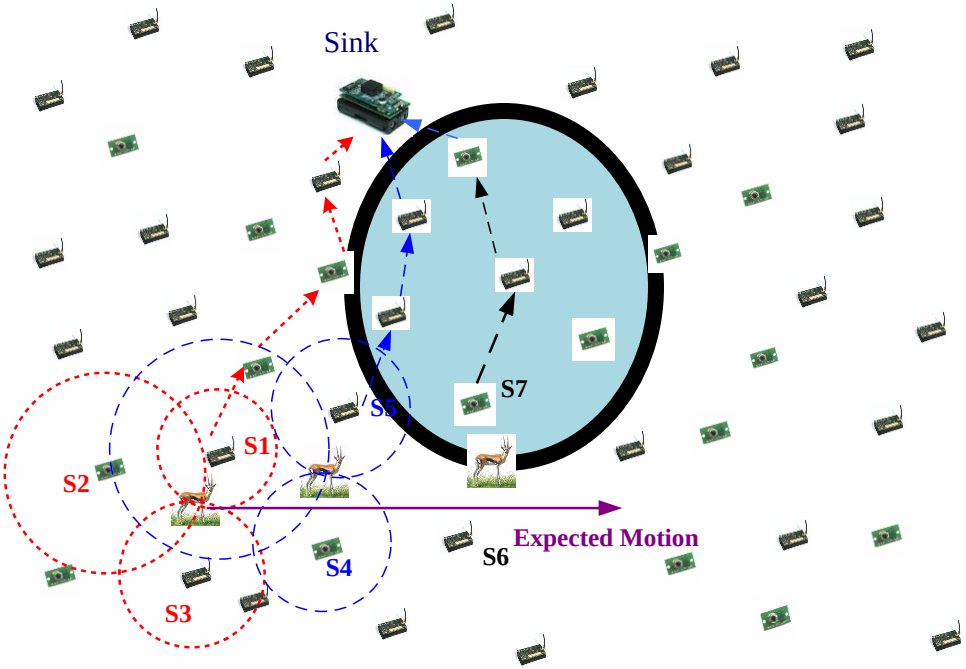


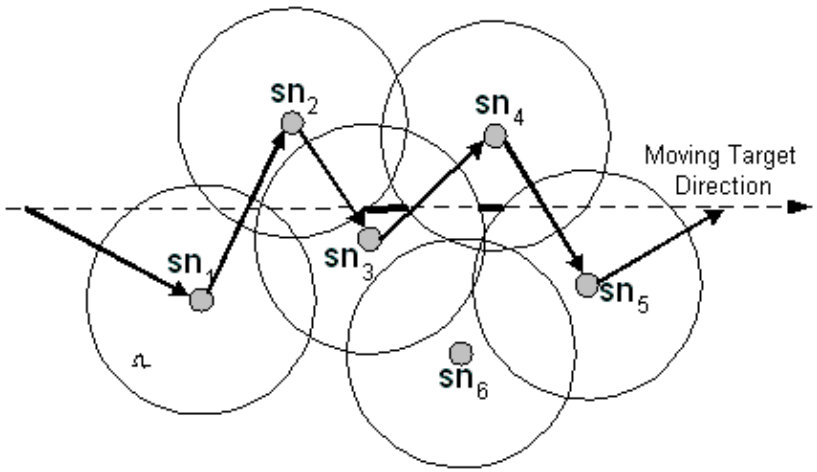


Tracking in WSN

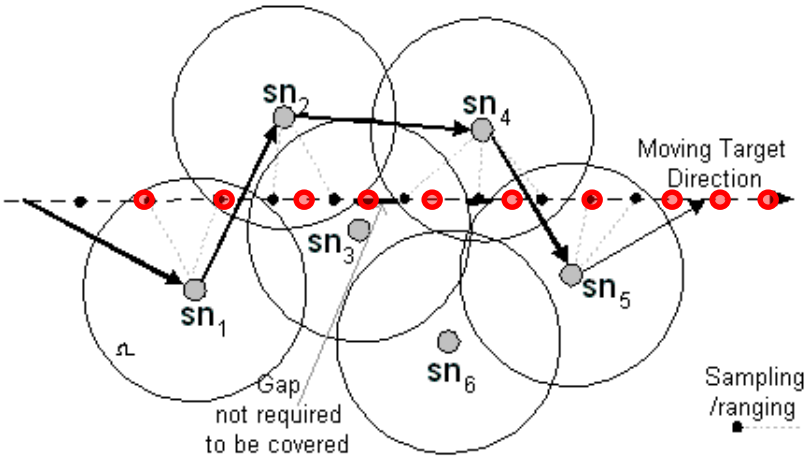
- Wireless Sensor Networks (WSN)
  - $10^2 – 10^3$ nodes capable of
    - Sensing
    - Computation
    - Self-organizing in a network
- Contexts:
  - Energy-sensitive
    - 2-3 orders of magnitude more "eaten up" by communication
  - Deployment
    - Irregular/Imprecise
    - Hostile environments
  - Queries' answers may be needed in dedicated ***sink(s)***
  - Trajectory determined by tracking
    - Location ← collaborative trillateration

Tracking and Trajectories in Sensor Networks





Continuous → 5



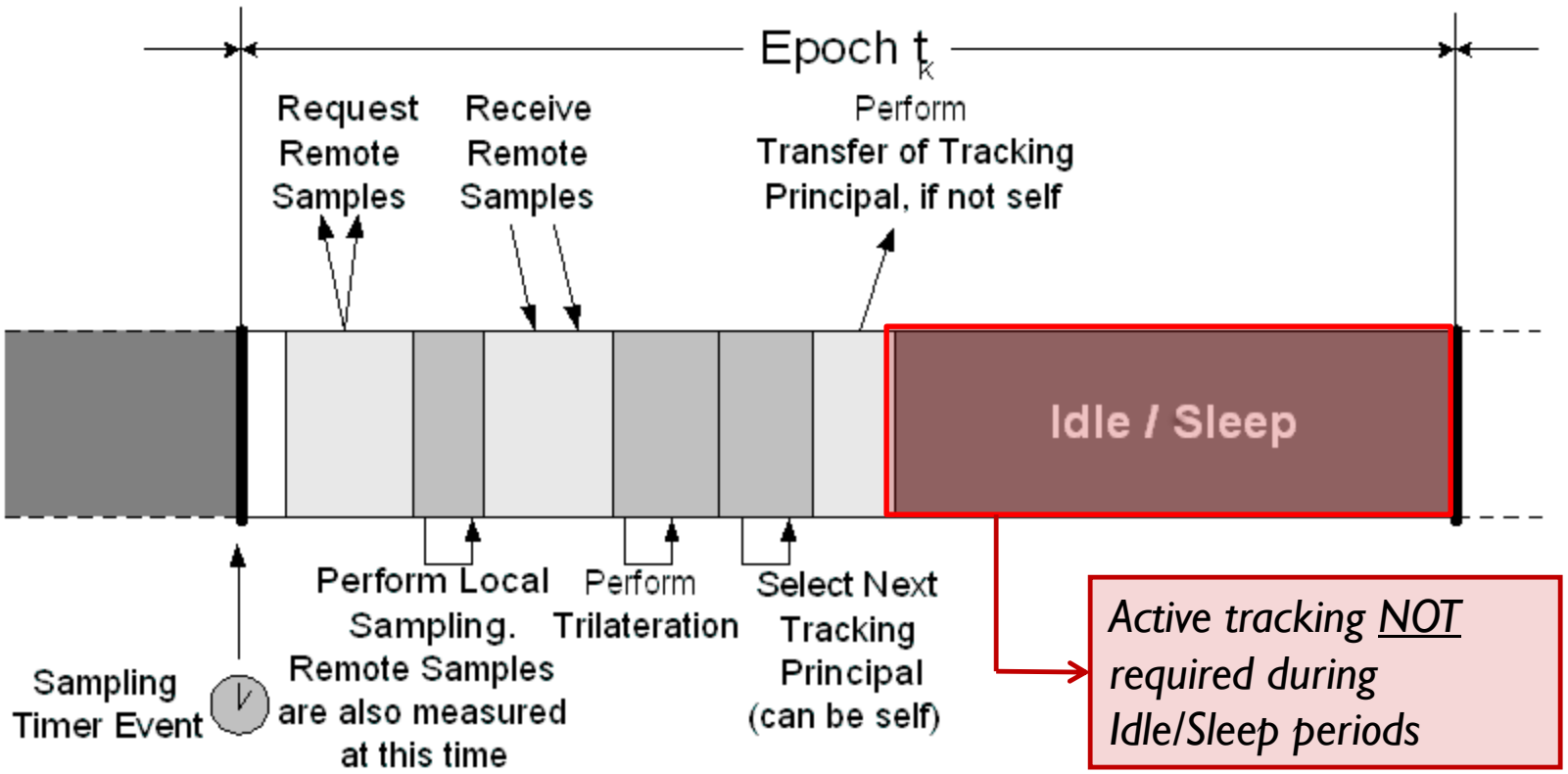
Discrete → 4

Tracking:

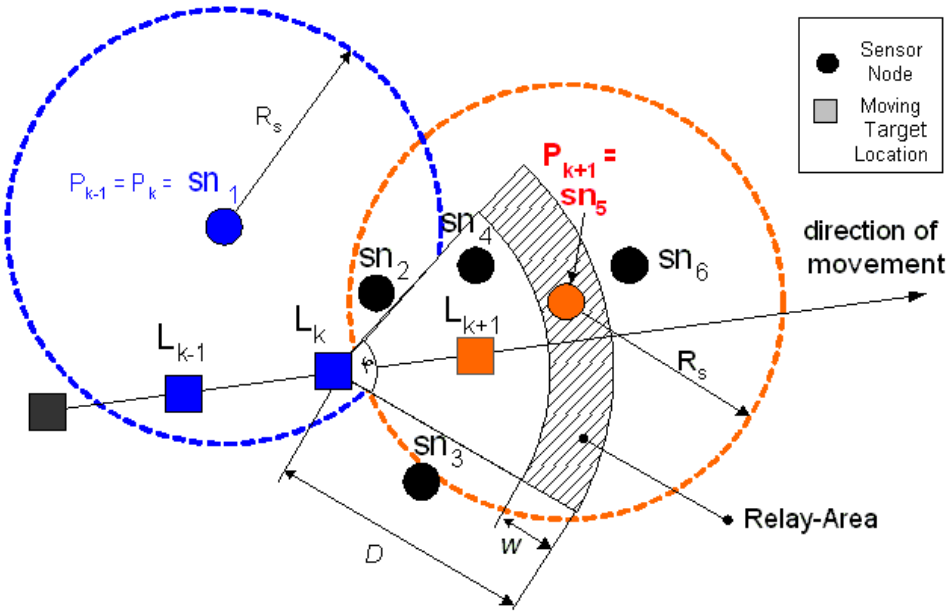
- Does every location-sample need to be transmitted?
- Who is the tracking principal?

Trajectories in Sensor Networks – Tracking Epoch Model

Epoch:
Discretely-synchronized time interval during which ranging measurements are aggregated to achieve *one* sample

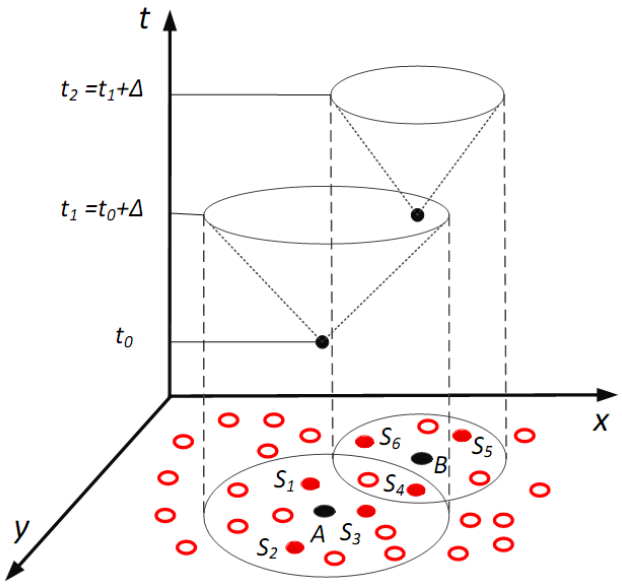


- Prediction Approach
  - *Current* Location
  - ***Predicted*** velocity
- **Goal**
  - Pick farthest node along the predicted trajectory to minimize number of hand-offs
- Mechanism:
  - Define a sector-area where ideally the best candidate principal node should reside

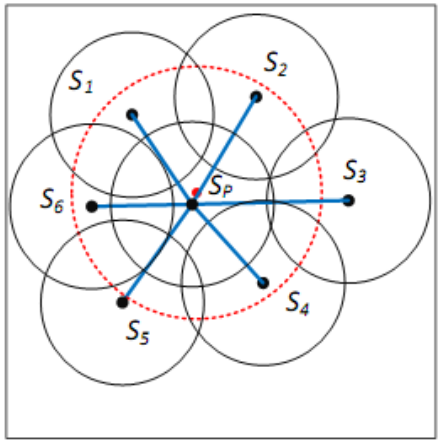


When target o_i approaches the limits of the sensing area L_k of the current tracking principal $P_k = sn_1$, based on velocity information, node sn_5 is selected as next principal P_{k+1}, which is located within the defined relay area

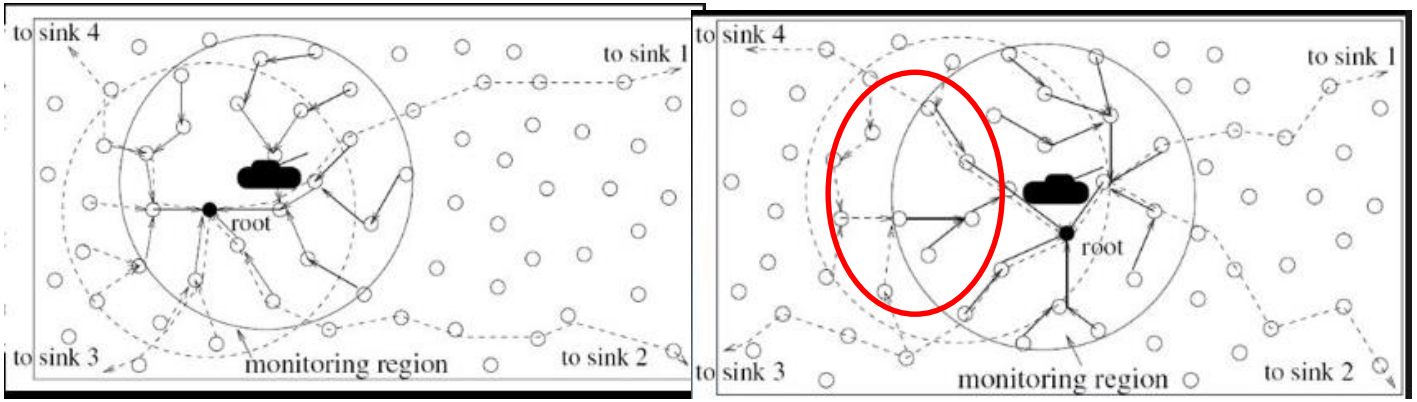
Using Uncertainty: Which nodes to awake during epoch-based tracking?



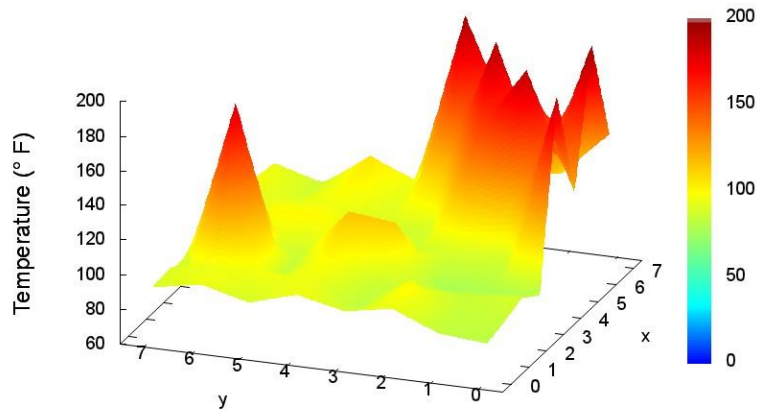
Minimum Disks Cover



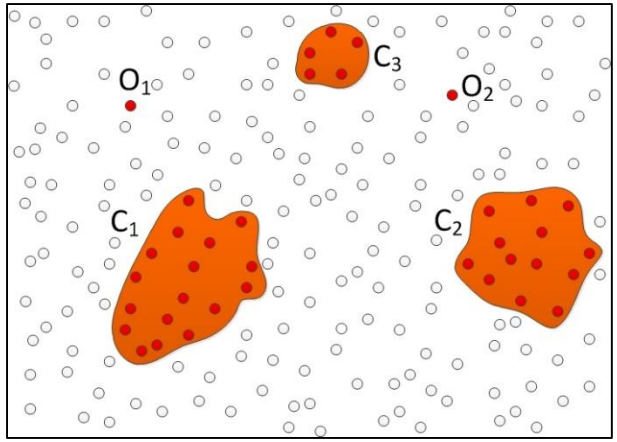
Tracking ⇒ adjusting of routing structures…



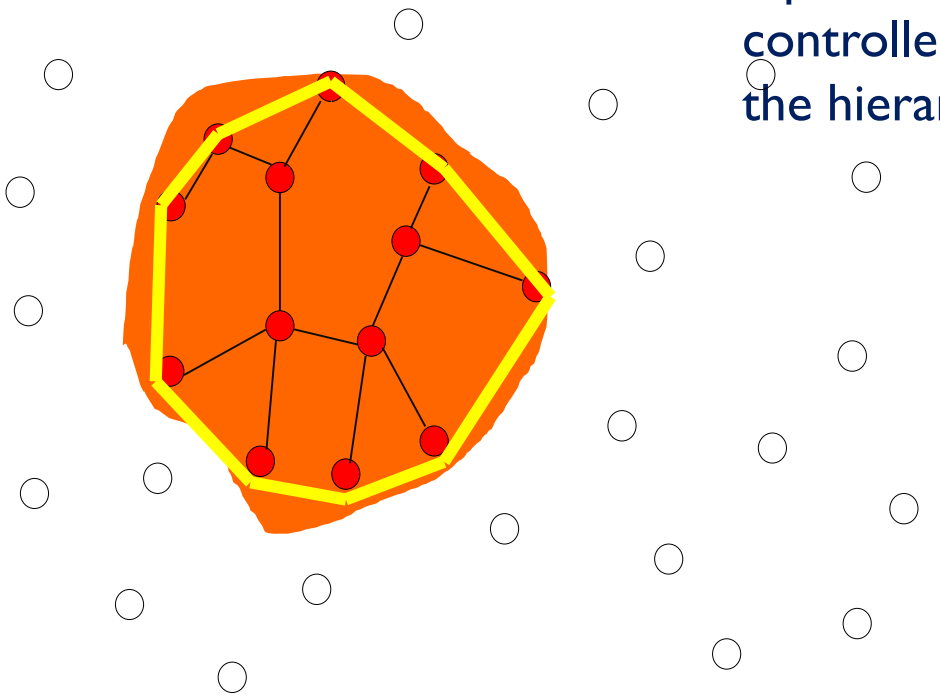
- Detect an occurrence of a shape S in the network such that
  - The area of S > A
  - The smallest value read by sensors in S is at least γ



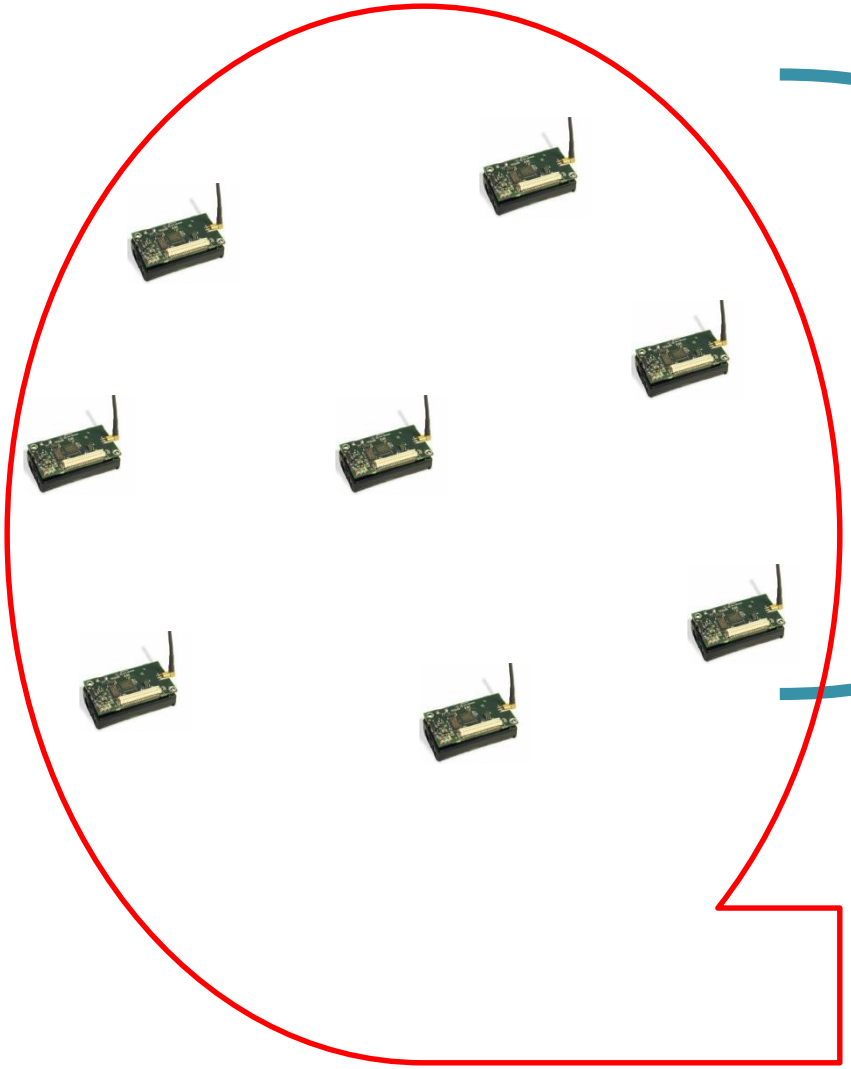
Tracking – WSN and Mobile Shapes



- Group relevant points via DBScan with density = 1, ε = sensing range.
- Apply χ –shape algorithm to approximate concave polygonal boundary.
- Calculate the area, discard if not large enough to satisfy the definition of the predicates.
- If partial shape is on the edge of the zone controlled by a local principal, forward it along the hierarchy



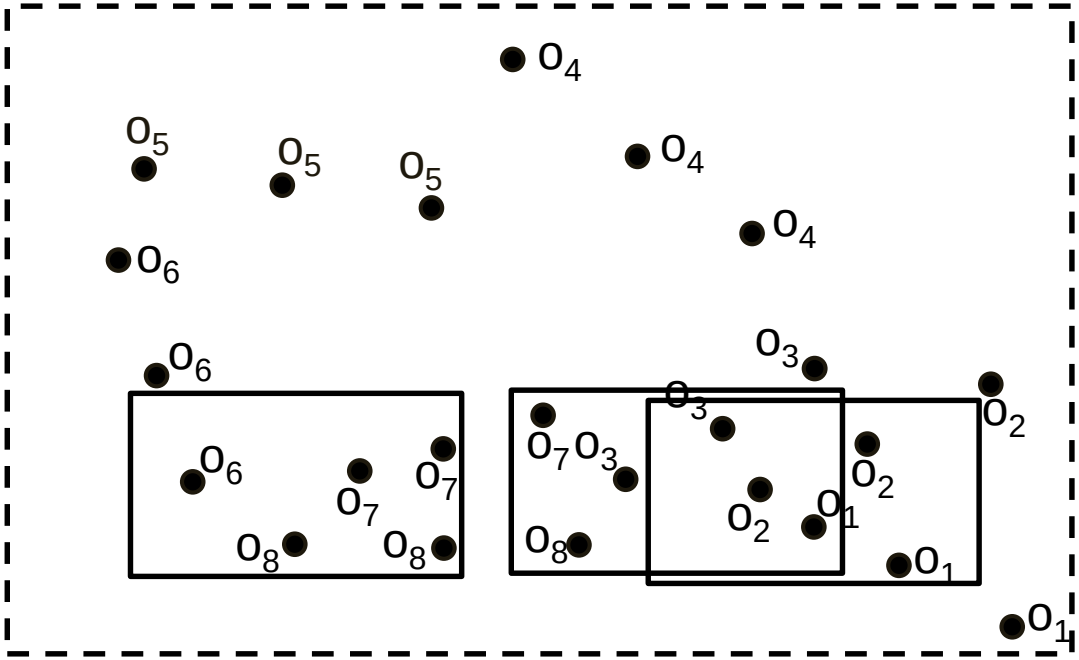
Mobile Data: WSN and Mobile Shapes



- Does one really need all the "evolutionary" events and predicate-changes to be reported?
- If not, what is the "…I can leave with…":
  - Probabilistic Syntactic Constructs/Semantics;
  - Implementation;

- Consider a rectangle that is FOV of a drone:

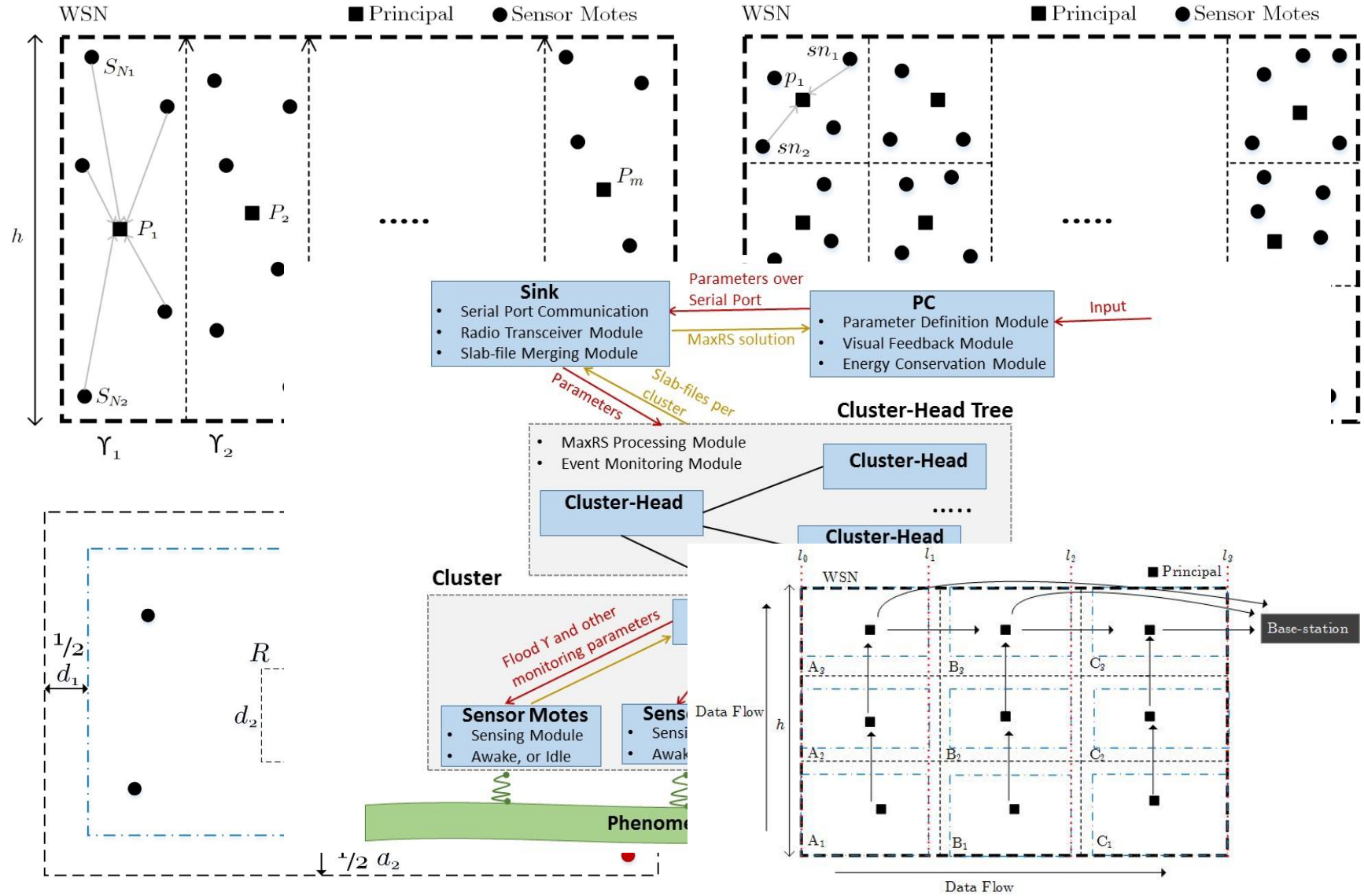
What should be the trajectory of the drone that ensures max. number of "objects" in its FOV?



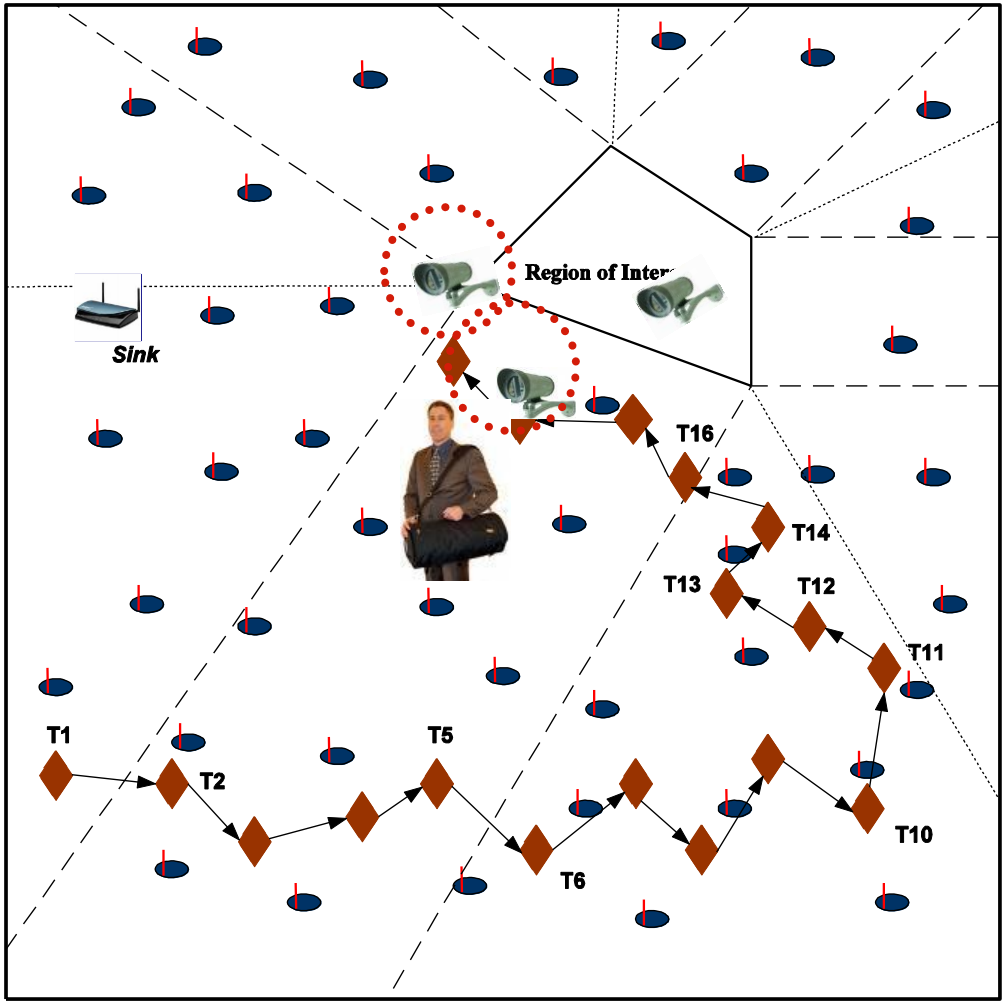
Object location at t_{max}

- **Continuous detection of "most interesting" regions for mobile entities**

Tracking Clusters Mobile Data: k-MaxRS in WSN



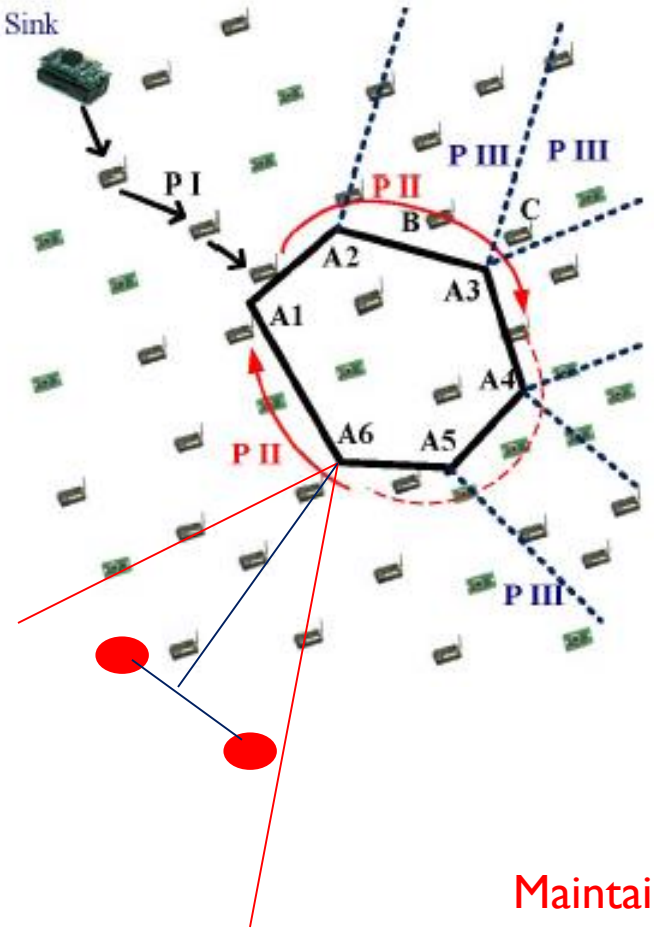
Tracking and Mobile Data: Push vs. Pull



"If an object has been continuously moving towards RI for more than 5min., begin tracking it with at least 2 cameras when it gets closer than 100 yards.

Subsequently, *if that object is identified as* human carrying a bag, *maximize the focus of the closest camera, and transmit its stream to the monitor in the closest patrol vehicle".*

Tracking and Predicates in WSN – Continuously Moving Towards (CMT)



Voronoi diagram of the query region;
Disseminate the boundary (edge or vertex) throughout the V-cell

Inside an edge-cell:

object can only move towards or away in-between successive location samples

Inside a vertex-cell:

similarly, except:
if the perpendicular to the line defined by consecutive location samples falls inside the segment, the object "flips"

Maintain a temporal-accumulator and update it with every new location sample

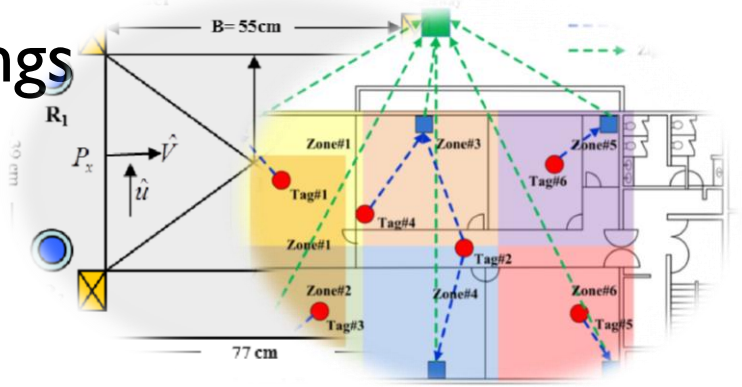
- add of moved towards and still does;
- reset to 0 if "flips" from towards to away

Observation:

consumption of primitive events?

Indoor Tracking

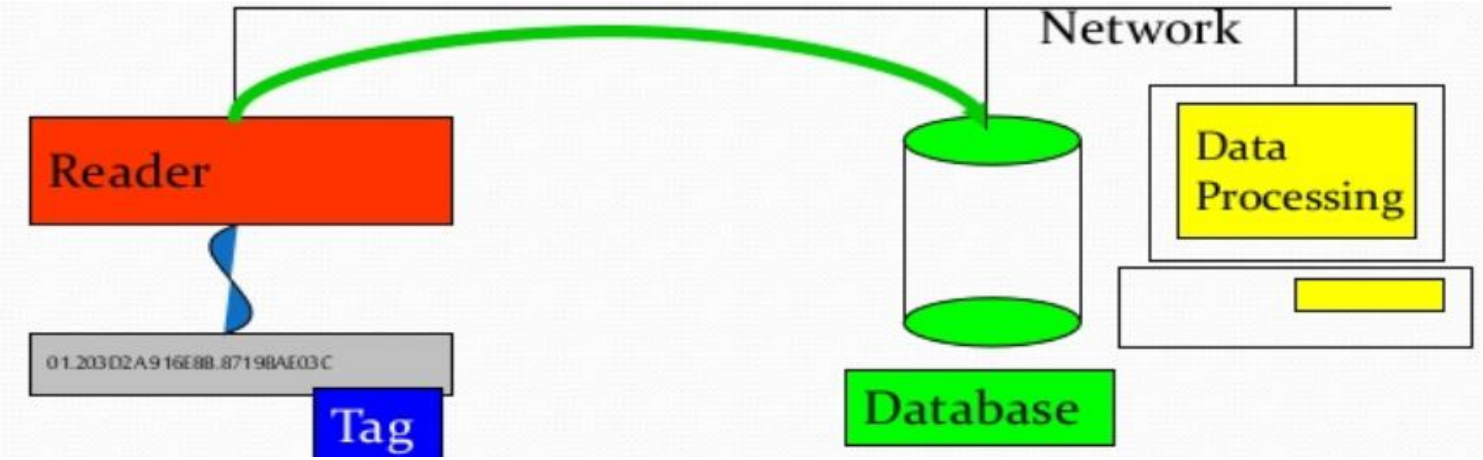
- GPS does not work inside buildings



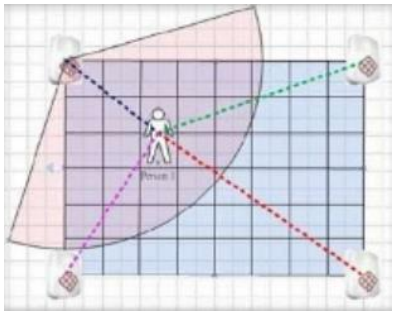
- Indoor LBS applications abound:
  - Navigation (people/robots)
  - Inventory
  - Patients/Staff
  - Ambient Intelligence
  - Luggage
  - …
- Coupled with other data
  - Floor-plans
- Must resort to other "tricks":
  - RFID based
  - Wi-Fi bases
  - Cameras

Indoor Tracking – RFID

- Relies on
  - Tags (transponders)
    - Active or Passive
  - Readers (transducers)
  - DB



- Typically, partitions space in grids
- Uses RSSI based "Euclidian" distance

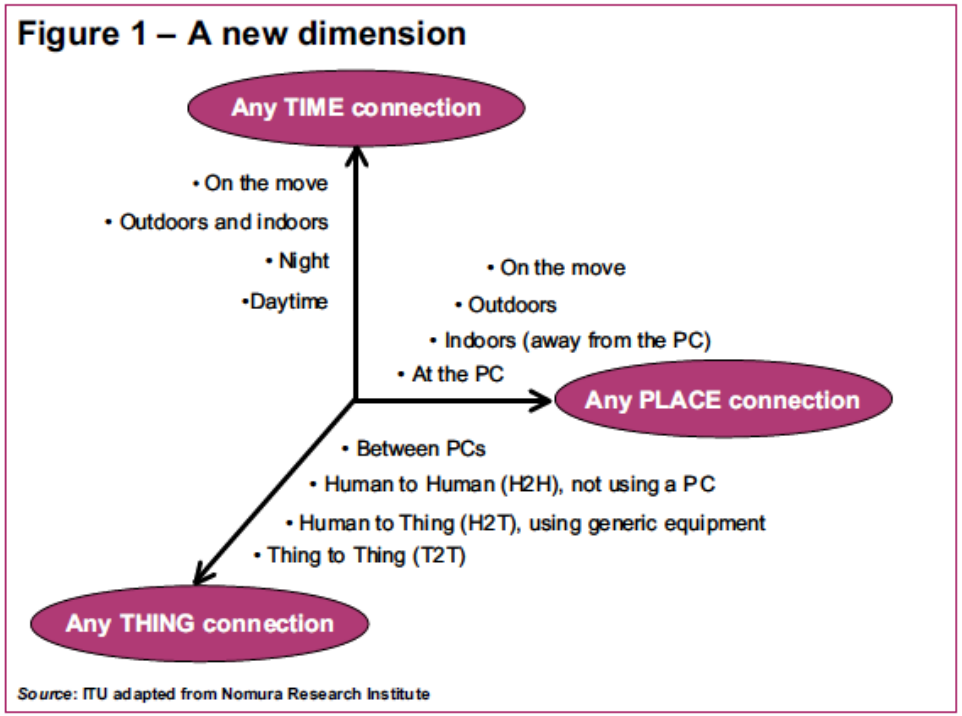


Indoor tracking – a RFID vs. Wi-Fi

- RFID:
  - Tracking of goods/people/animals/books/luggage; Travel documents; Car keys
  - Features:
    - Contactless; Re-Writeable; Data ranges/capacity; No LOS; Multi Tags

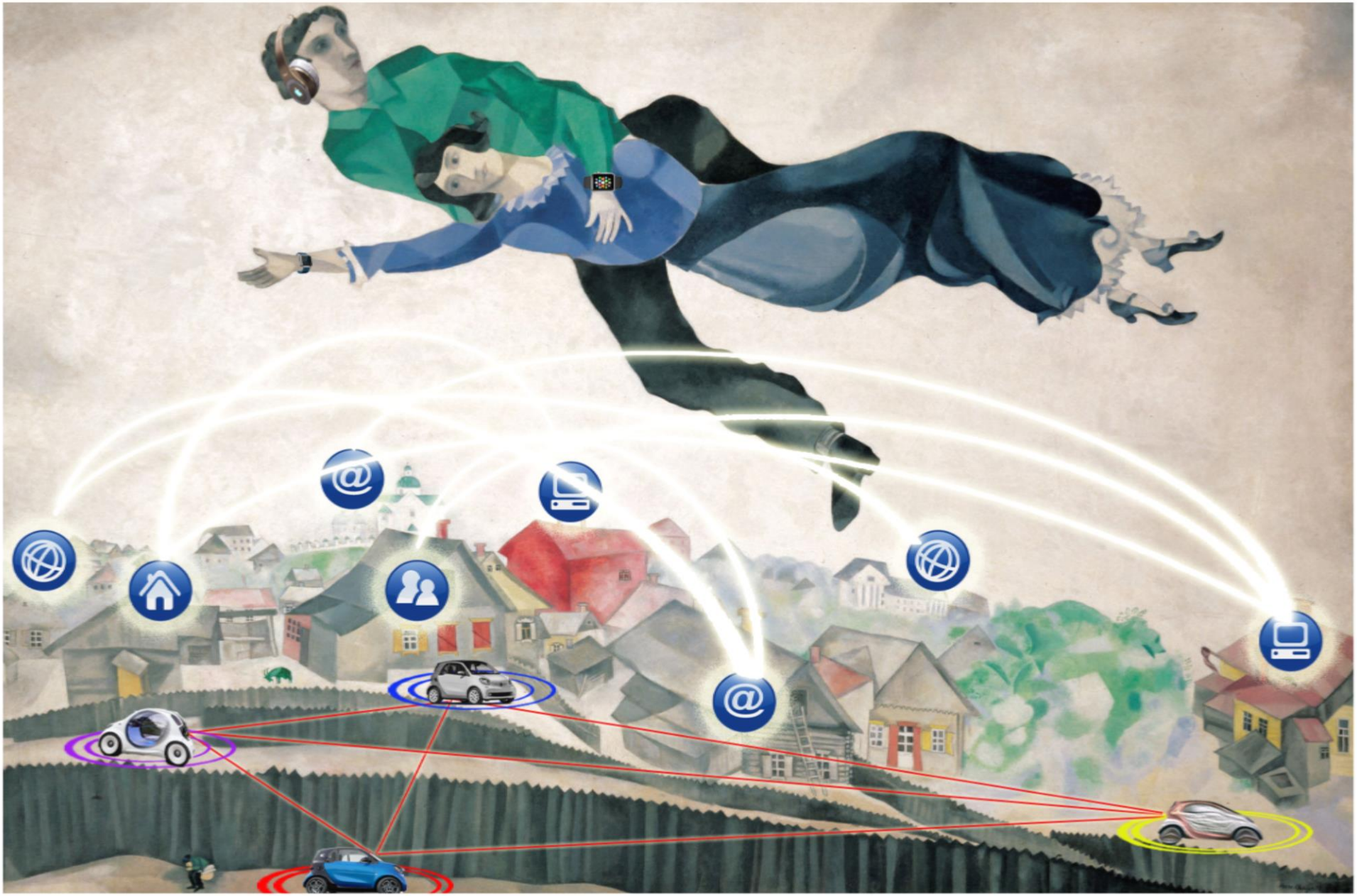
- Wi-Fi:
  - Similar tracking-domains and (high-level) architecture/components
  - However:
    - Bulkier devices; More expensive hardware
    - Often, fingerprinting required; (k)NN algorithms used for distance
    - Suffer more from interference (Access points); Smaller range
    - ***Much higher transfer rate/bandwidth***
    - ***Better Security (RFID can be easily cloned)***

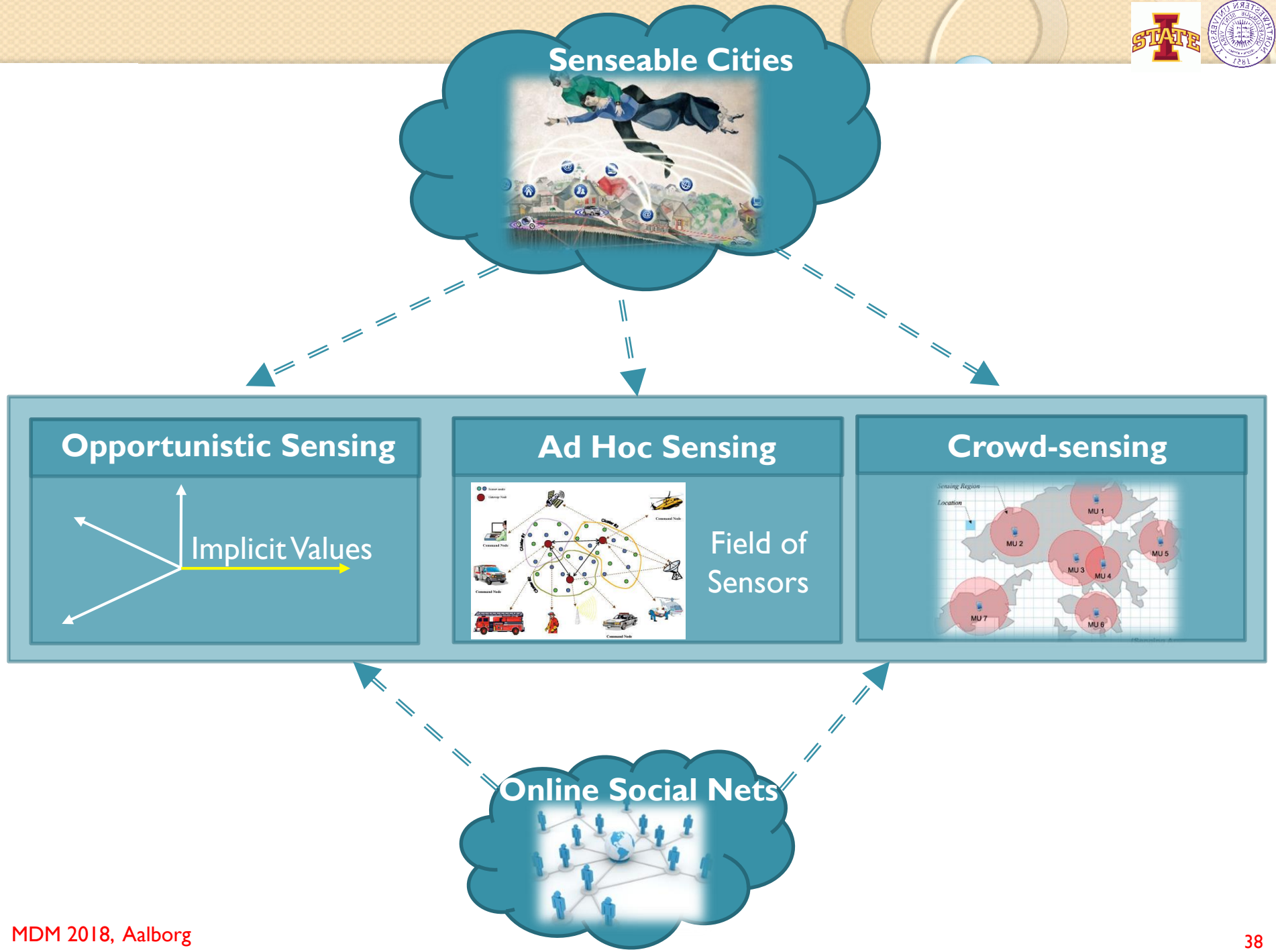
Tracking in the IoT world…



- Heterogeneity of devices;
- Semantics;
- Coupling(s) between:
  - Data;
  - (Predictive) Analytics;
  - Feedbacks/Actuations
    - Changing the operating regime of the very devices that gather the data…
    - Typically, ~O($10s) per "device"…

Senseable Cities




Senseable Cities
Opportunistic Sensing
Implicit Values
Ad Hoc Sensing
Field of Sensors
Crowd-sensing
Sensing Region
Location
MU 1
MU 2
MU 3
MU 4
MU 5
MU 6
MU 7
Online Social Nets

Tracking Boundaries and Topology of Spatial Regions

- **Boundary estimation and tracking**–predict as many points on the boundary in order to estimate it.
- **Boundary covering—locate** the points on the boundary and physically surround it => can only be done by mobile sensors.
- **Contour definition** : set of points with a given field value.
  - ❑ **Problem definition** : estimate the contour with mobile sensors with maximum precision and minimum latency in tracing it.

Step 1: Converge Phase

1. Direct Descent *DD*

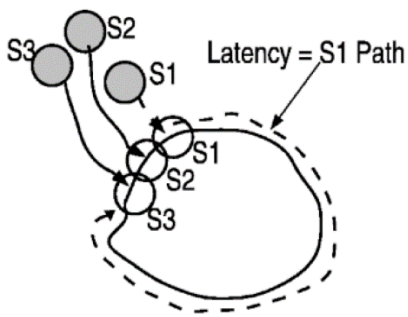
Choose direction that minimizes the **distance function**

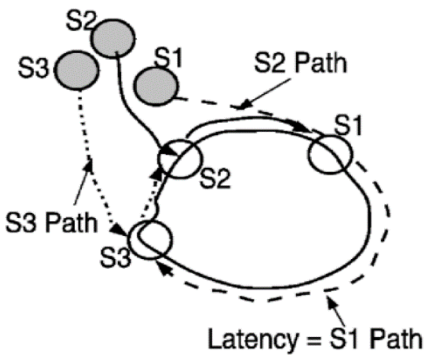
$$d_f = (1 - \frac{f}{\tau})^2 \qquad if\ f(x,y) \le \tau$$

$$d_f = (1 - \frac{\tau}{f})^2 \qquad else\ f(x,y) > \tau$$

- *f(x,y)* is field value at location (x,y); τ is the contour field value

Latency high when sensors are collocated and contour is big. **Need to spread!!**



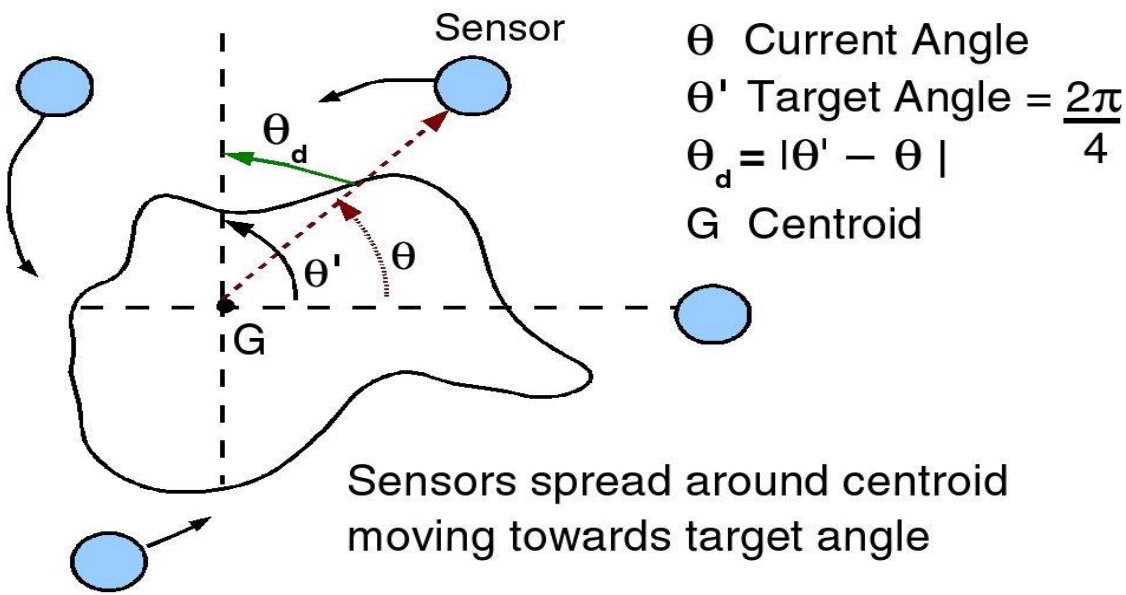


S. Srinivasan, K. Ramamritham and P. Kulkarni, "ACE in the Hole: Adaptive Contour Estimation Using Collaborating Mobile Sensors," *Proc. IPSN 2008*

Step 2: Spread Always (SA)

- Choose direction that minimizes spread function s_f that measures how far sensor is from target angle $\theta' = 2\pi/N$

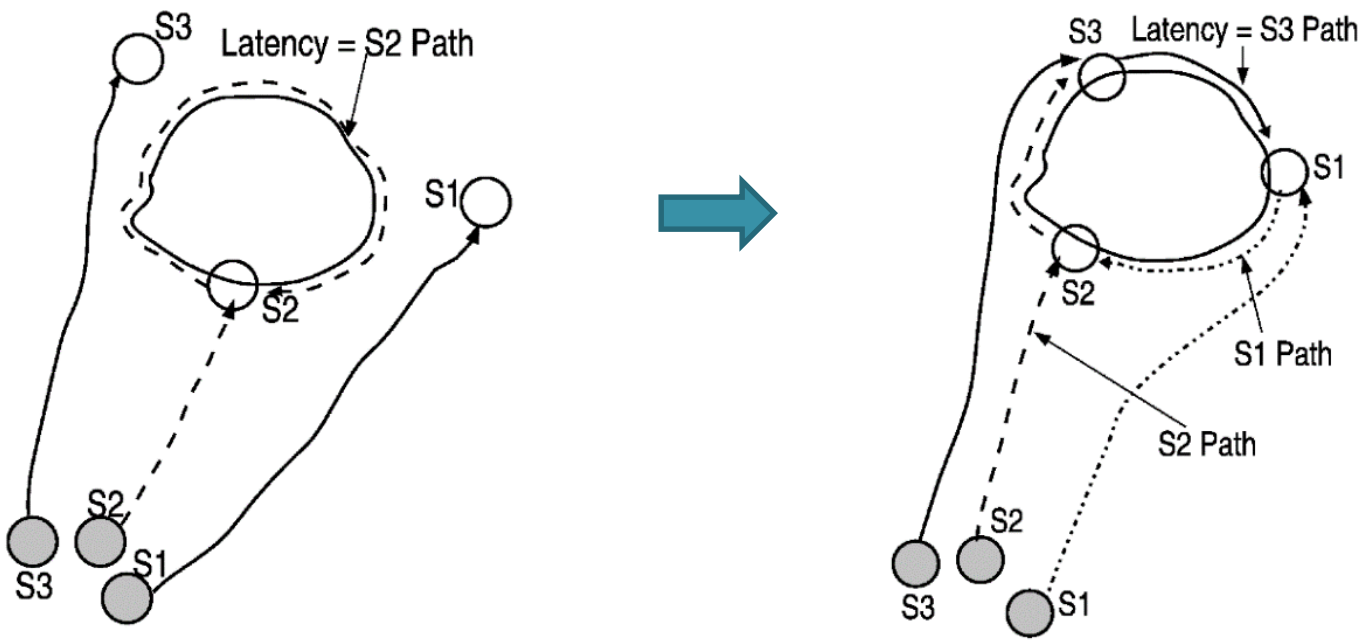
$$s_f = \left(\frac{\theta_d}{2\pi}\right)^2$$



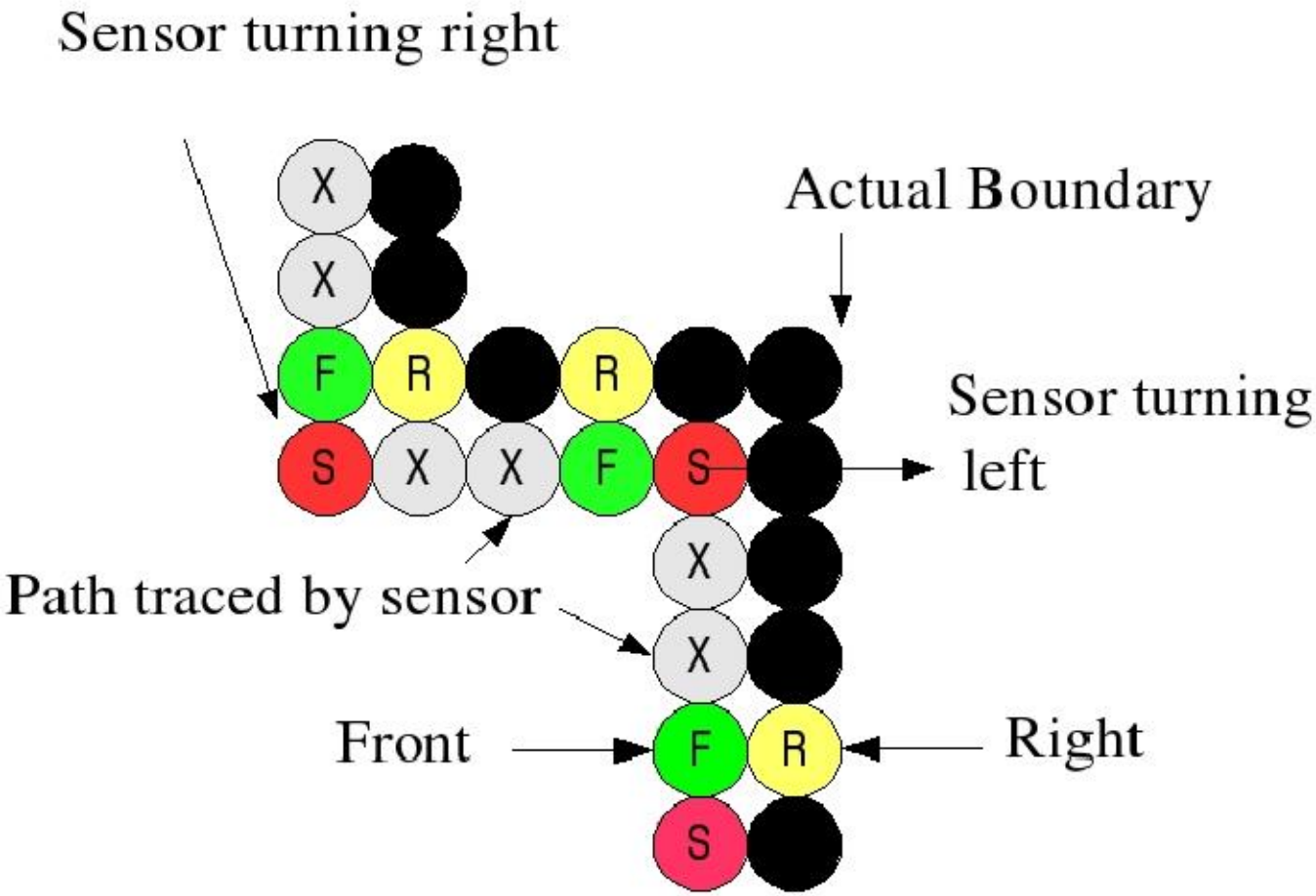
Problem with SA

Latency is high when sensors are deployed far and contour is small—some sensors fail to converge

Adaptive algorithm considers extent of sensors spread, size of contour and distance of sensor to contour.



Use Wall Moving Algorithm to trace



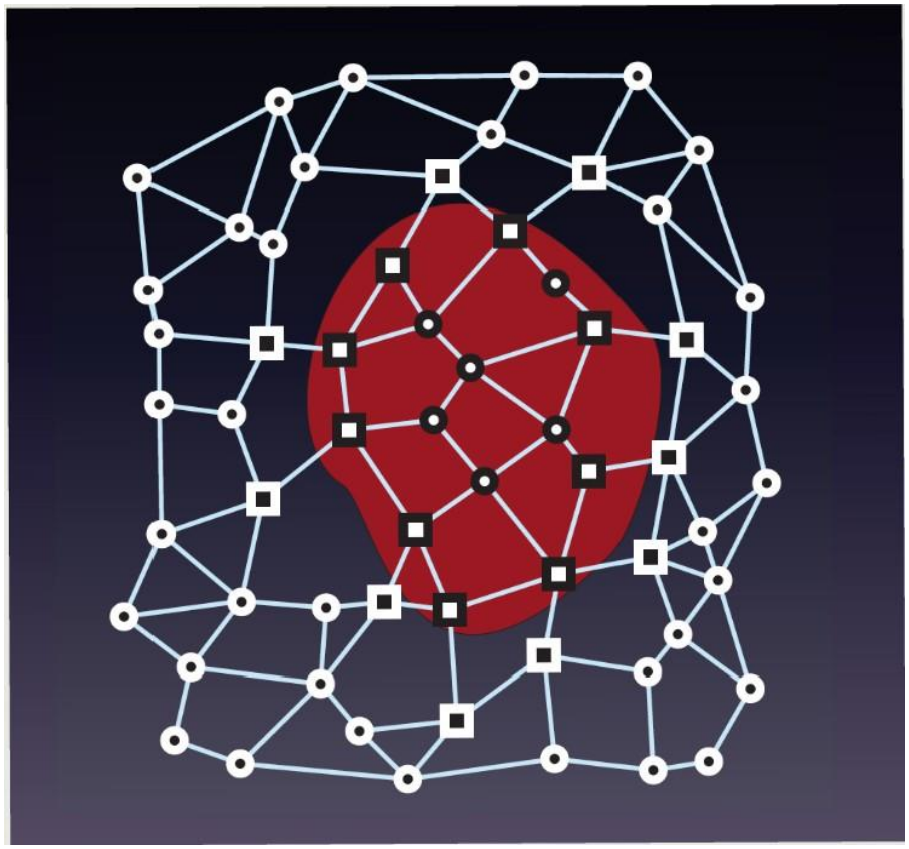
Detecting the Topology of Areal Objects

- **Main Idea: Three levels of boundary structures**
  - Boundary Nodes
  - Boundary Cycles
  - Boundary Orientation

- Decentralized Algorithm for construction can be used to answer topological queries, e.g. containment and adjacency of regions

M. Duckham, D.Nusbaum, J.R.Sack, and N. Santoro, "Efficient Decentralized Computation of the Topology of Spatial Regions," *IEEE Transactions on Computers*, Vol. 60, No.8, August 2011,

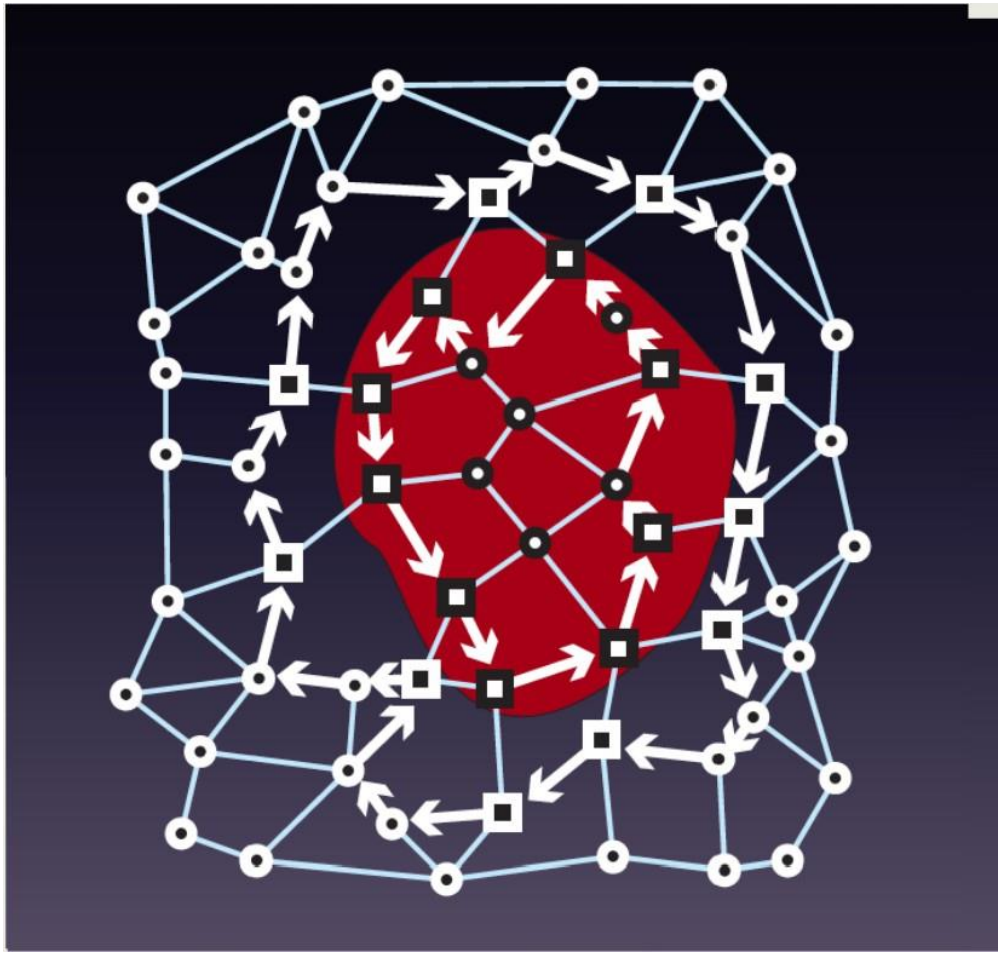
Graph with two region components and two boundary cycles



- **Boundary Node Detection**
  Sense whether you are in or out of the region (boundary node has at least one-hop neighbor with a different sensed value)
  - If you are outside, ask your immediate neighbors (Left, right, in front, behind) if anyone is inside.
  - No routing is necessary

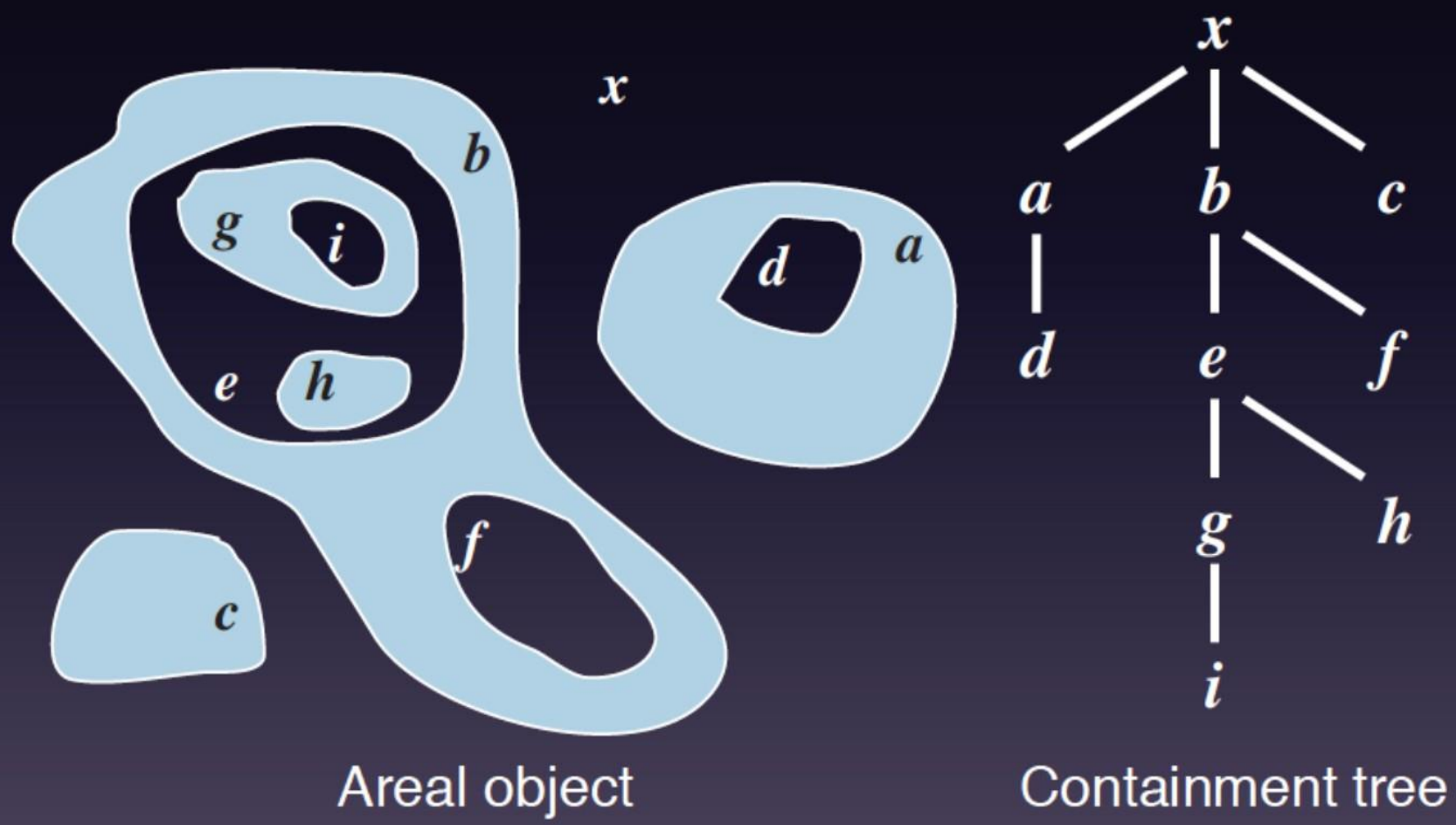
Boundary cycles constructed by adaptation of face routing—faces induced by region components

Computation for Boundary orientation—leader of boundary cycle initiates computation and sum is passed around the boundary cycle



$$\textit{area(P)} = 1/2 \sum_{i=1}^{n-1} X_i Y_{i+1} - X_{i+1} Y_i$$

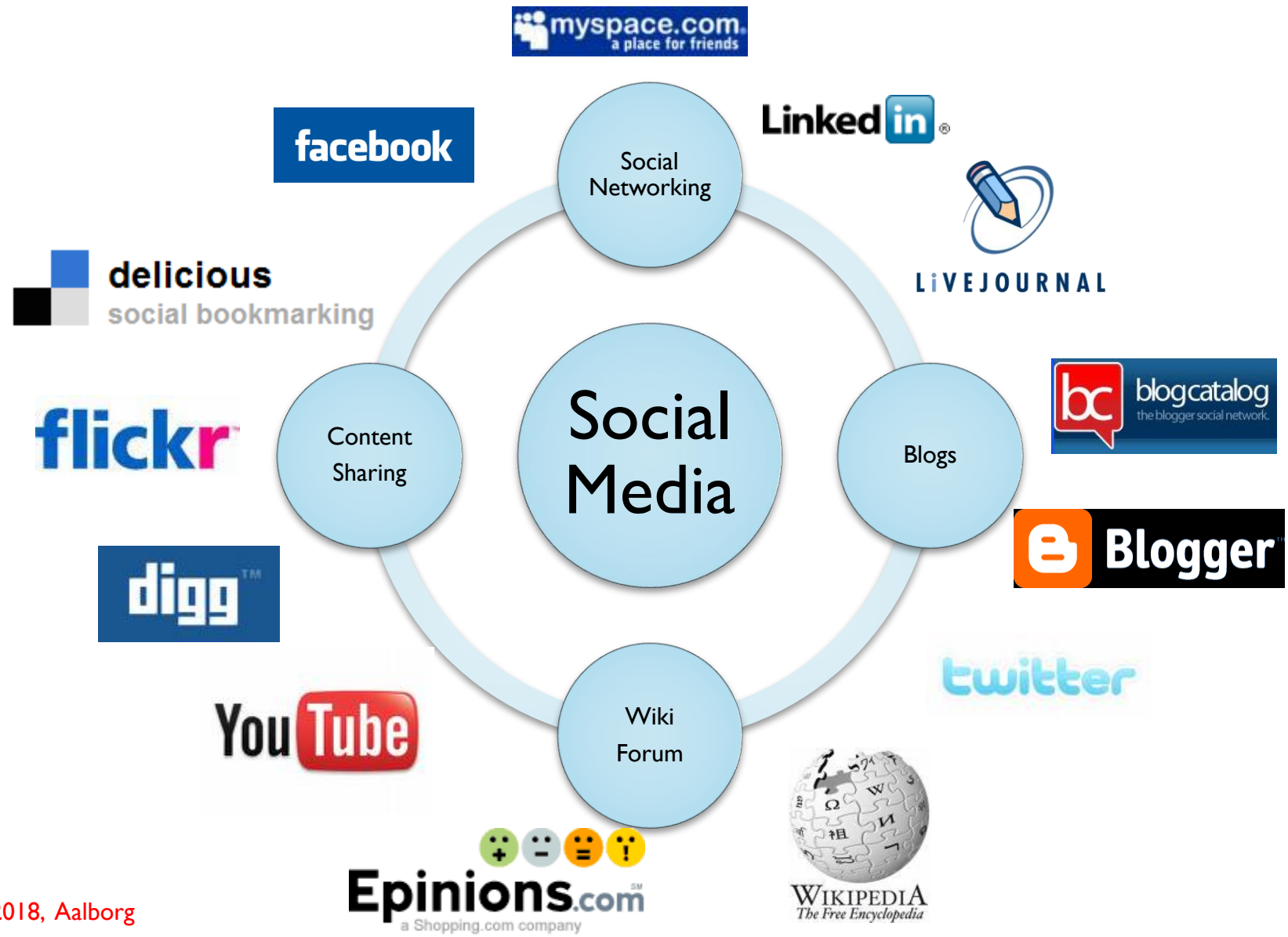
How to generate the containment tree for a complex areal object?



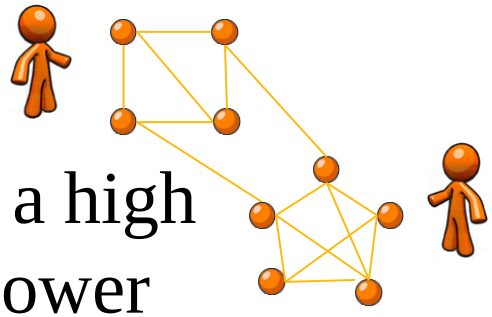
Decentralized IN-TORQUE protocol

- Uses variant of *semiline* containment algorithm
- Algorithm routes a message from each *boundary cycle leader to* the exterior updating the message at each boundary node encountered with information about the number boundary cycles passed.
- Boundary orientation is used in order to distinguish an outer boundary (of a region) from the inner boundary (of a hole)

Tracking and Social Networks

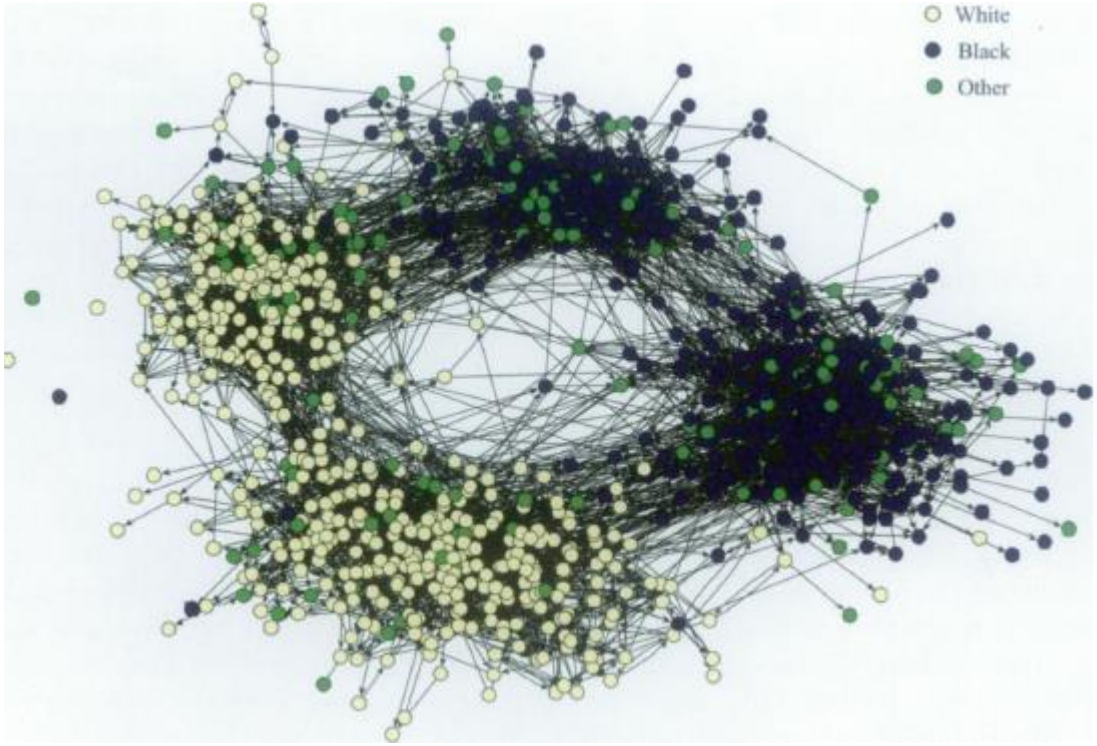


Community structure in social networks

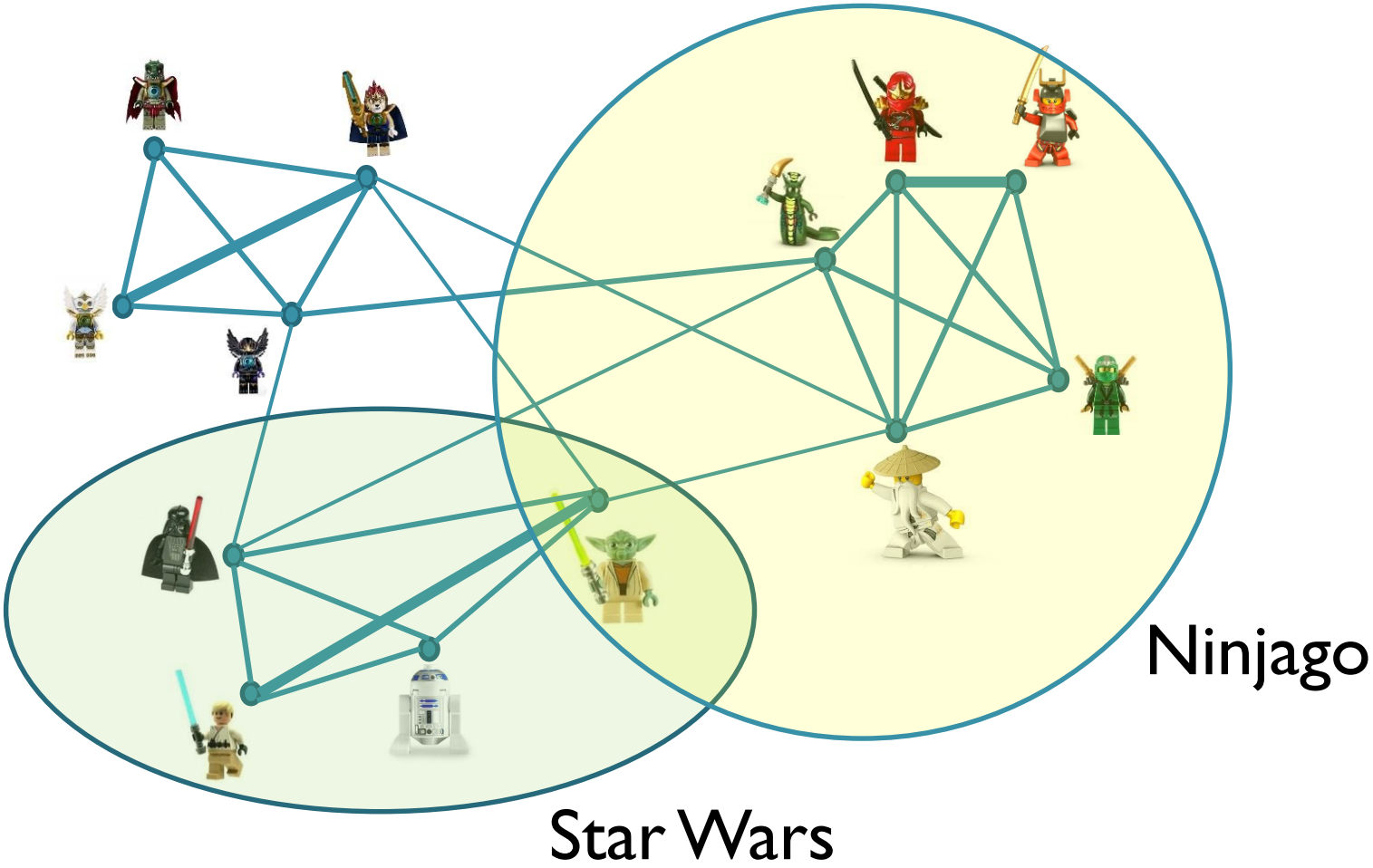


- Groups of people in the network that have a high density of connections within them and a lower density of connections between them

Friendship network of children in a US school



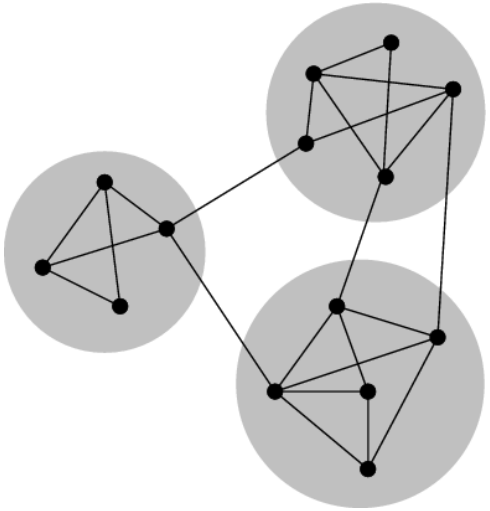
Communities Example (overlapping)

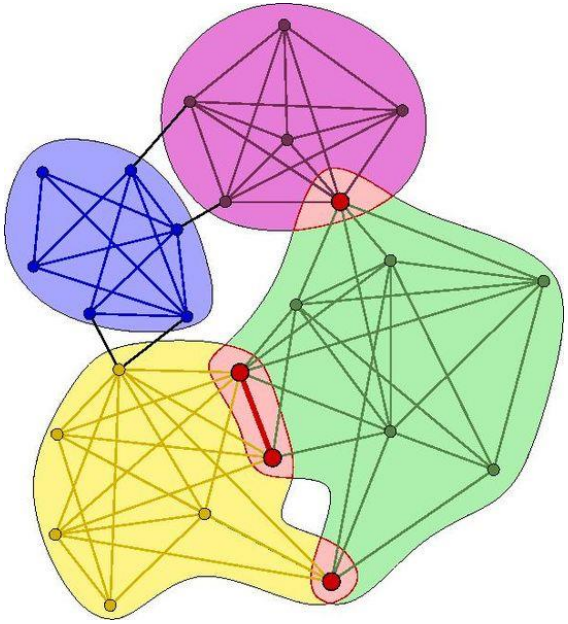


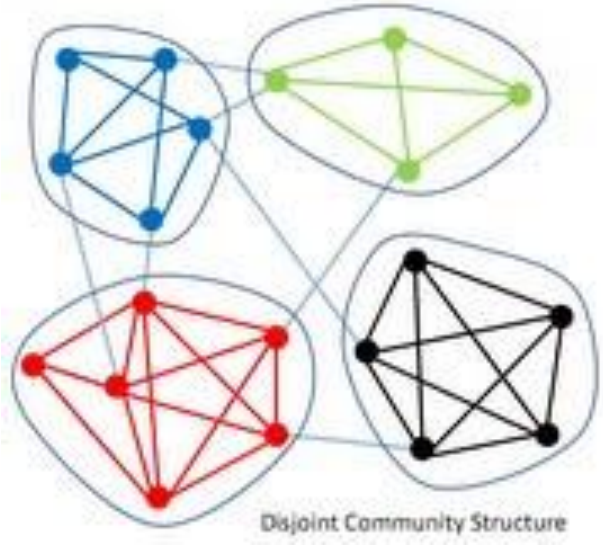
Community structure

* http://en.wikipedia.org/wiki/File:Network_Community_Structure.png

- No formally -defined concept(s) yet
- Densely connected inside each community
- Less edges/links crossing communities

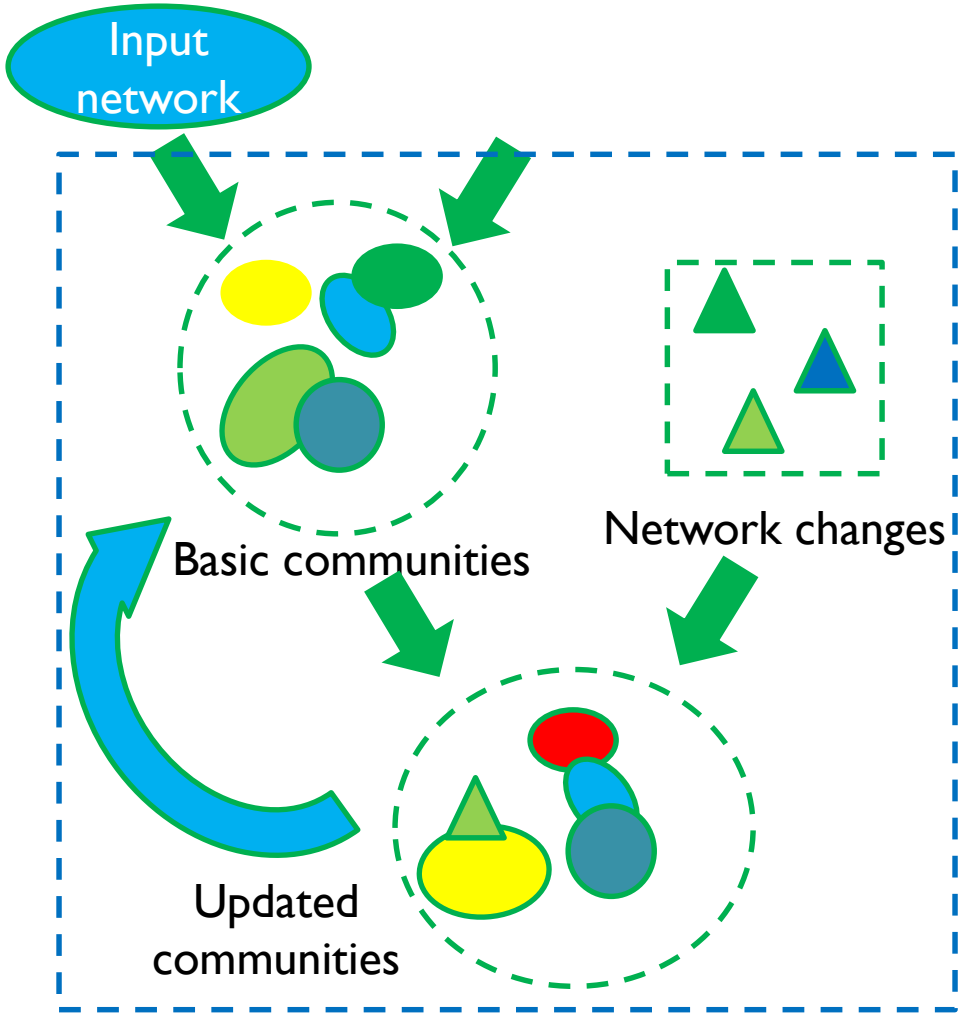






An adaptive algorithm for Community Detection (AFOCS)

N. Nguyen, T. Dingh, S. Tokala and My Thai, "Overlapping Communities in Dynamic Networks: Their Detection and Mobile Applications," *Proc. Mobicom 2011*

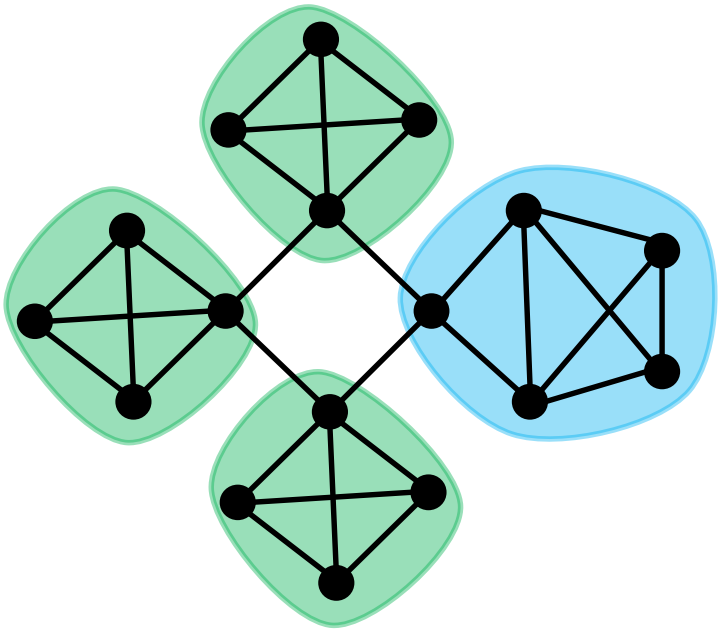


AFOCS:

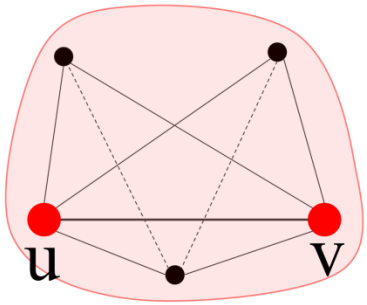
A 2-phase and limited input dependent framework

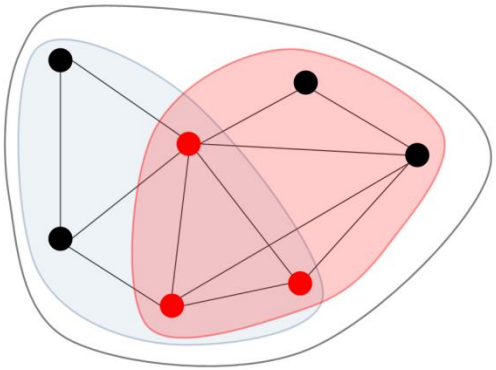
Phase 1: Basic communities detection

- Basic communities
  - Dense parts of the networks
  - Can possibly overlap
  - Bases for adaptive CS update



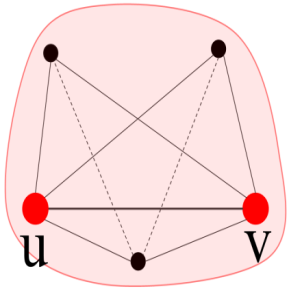
- Duties
  - Locate basic communities
  - Merge them if they are highly overlapped





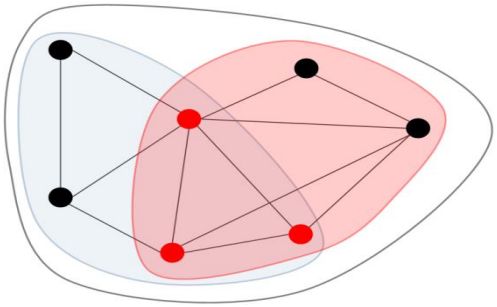
Phase 1: Basic communities detection

- Locating basic communities: objective function aims to maximize internal density
- Given (u, v) compute ψ the number of internal edges in its induced subgraph. If ψ exceeds a threshold τ graph is a local community



$\Psi(C) = 0.9 \geq \tau(C) = 0.725$

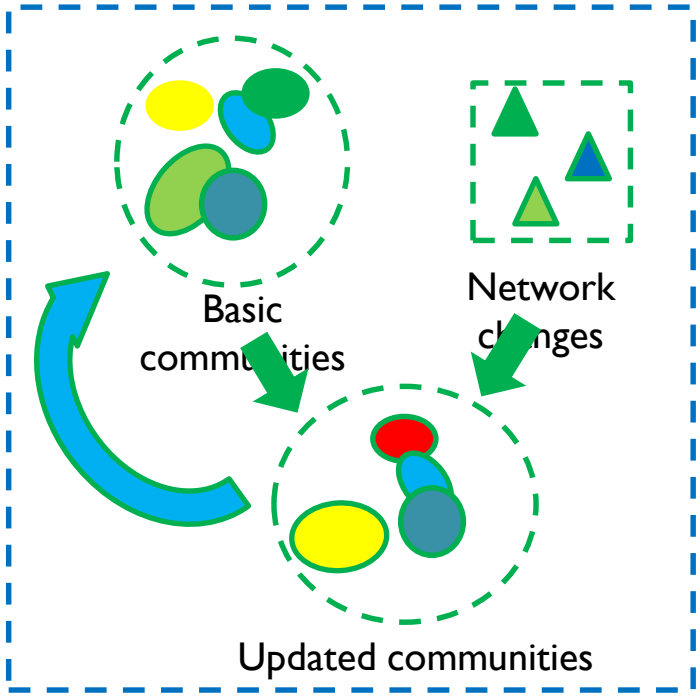
- Merging: distance metric **$OS(C_i, C_j) \geq \beta$** – overlap function considers both no. of nodes and edges in common



C_i and C_j have 3 nodes + 3 edges in common

Phase 2: Adaptive CS update

- ***Update network communities when changes are introduced***



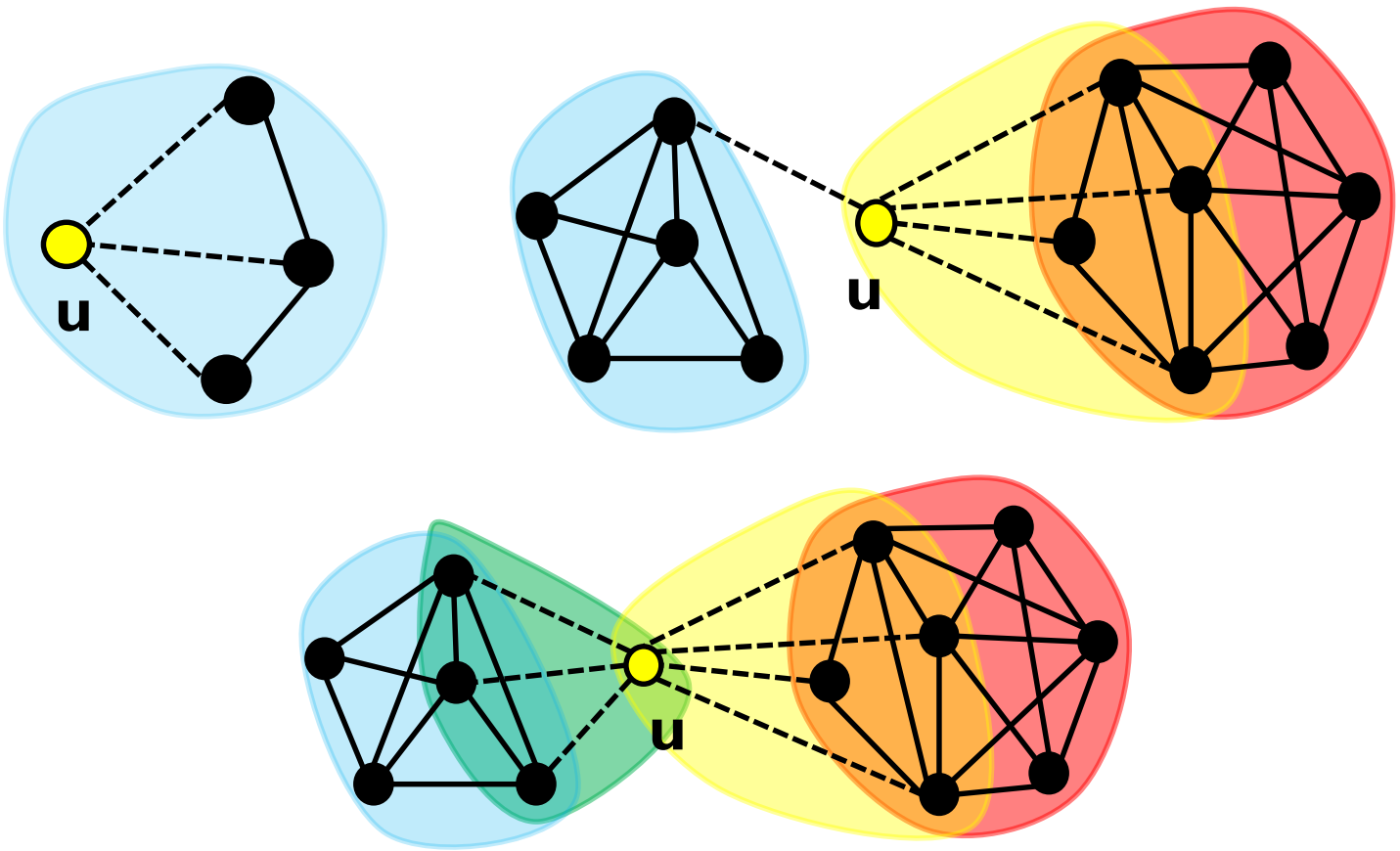
Need to handle

- Adding a node/edge
- Removing a node/edge

+ Locally locate new local communities

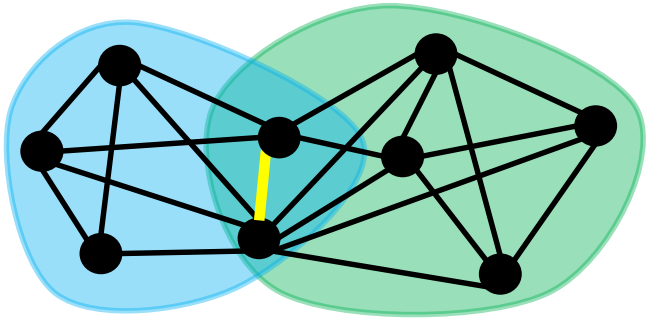
+ Merge them if they highly overlap with current ones

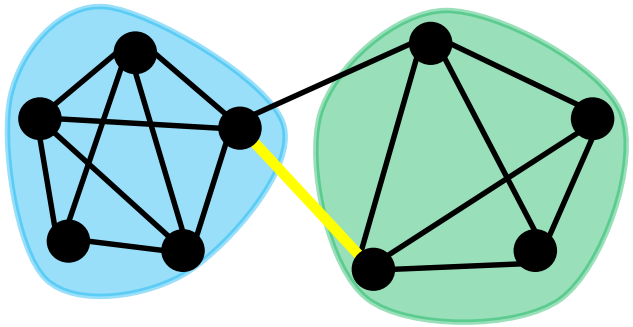
Phase 2: Adding a new node



Which community should u join to maximize the gained internal density ?

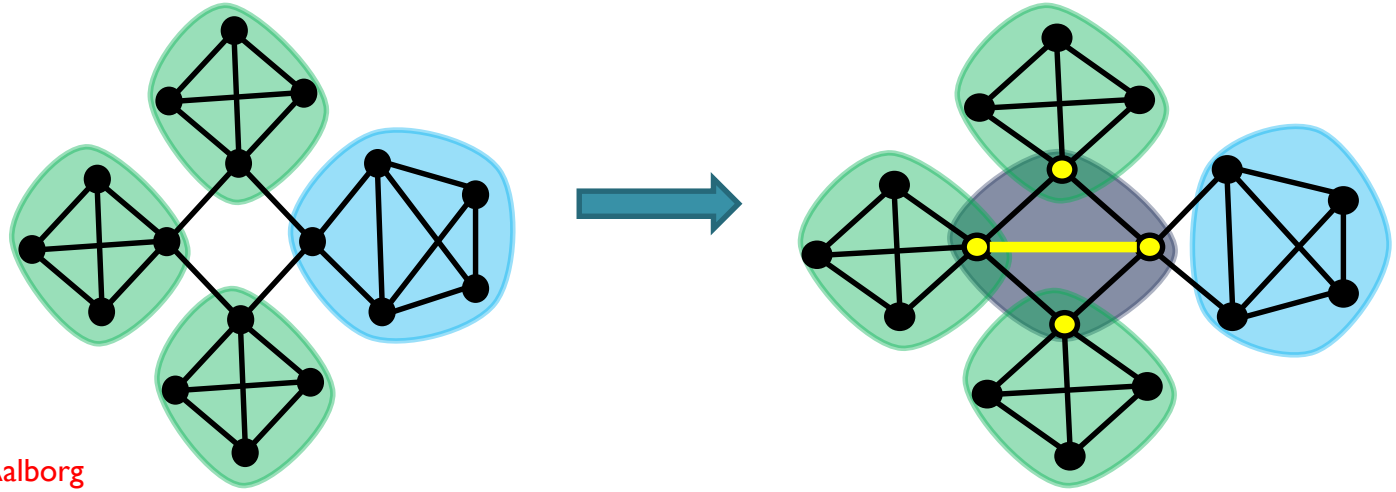
Phase 2: Adding a new edge



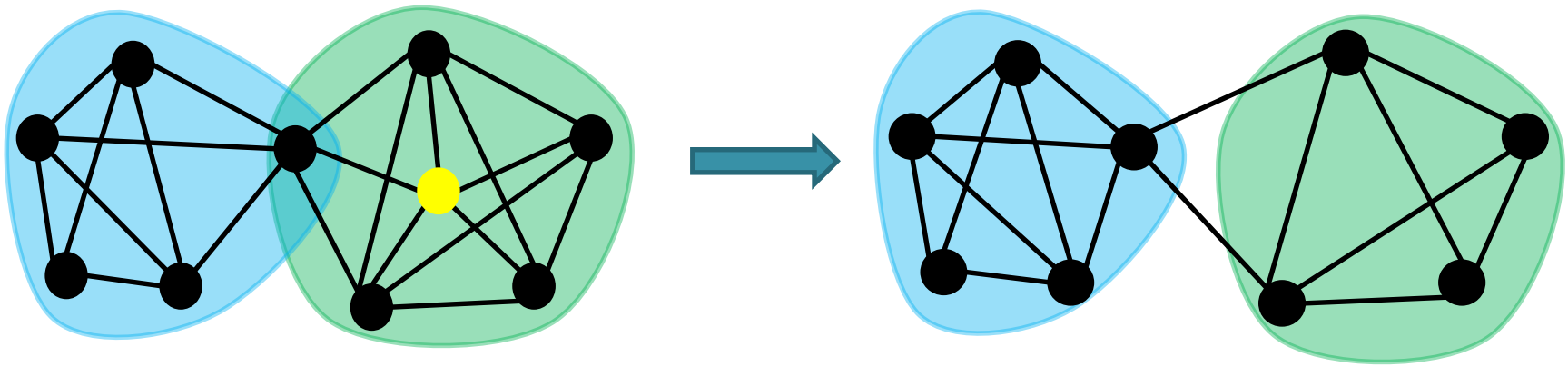


If a new edge *(u,v)* is introduced solely inside a community C, it should not split C into smaller substructures

When a new edge *(u.v)* is introduced between two disjoint communities C_u and C_v neither *u* nor *v* should be moved to C_u or C_v



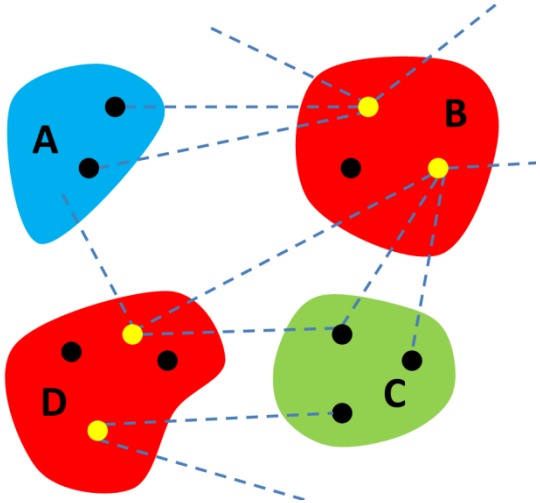
Phase 2: Removing a node



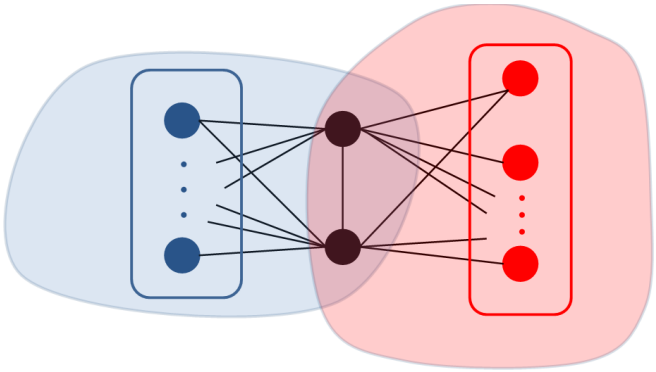
- Case above keep community structure intact
- If internal density is not sufficient identify the left-over structure(s) on C\{u}
- Merge overlapping substructure(s)

Application: Worm containment methods in cellular networks

- Available methods (cellular networks)
  - Choosing people/devices from ***different disjoint communities*** and send patches to them

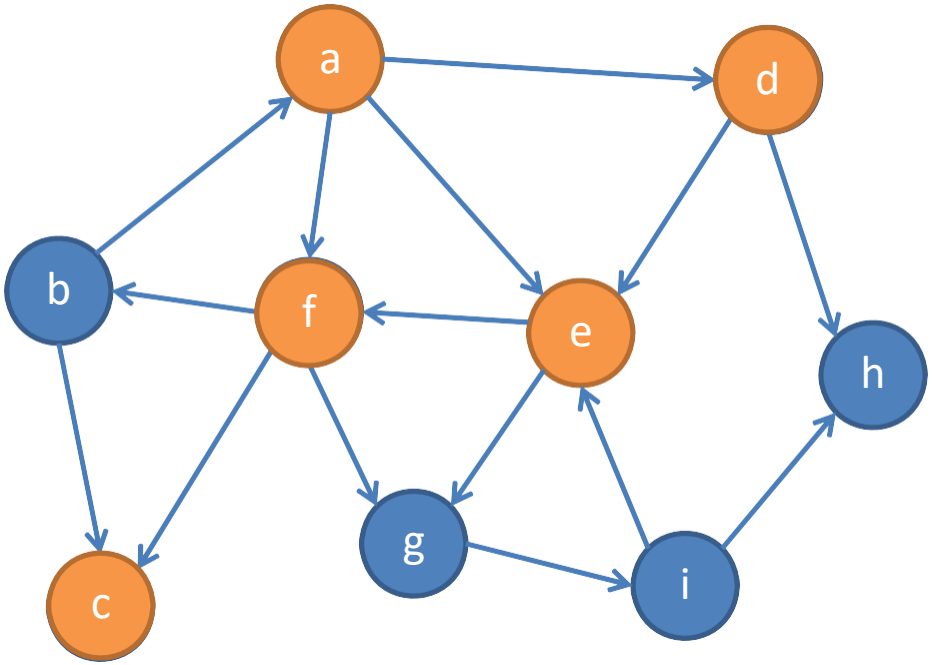


- Community Based method
  - Choosing the people/devices in ***the boundary of the overlap*** to send patches & have them redistribute the patches



Influence Maximization and Diffusion in Networks

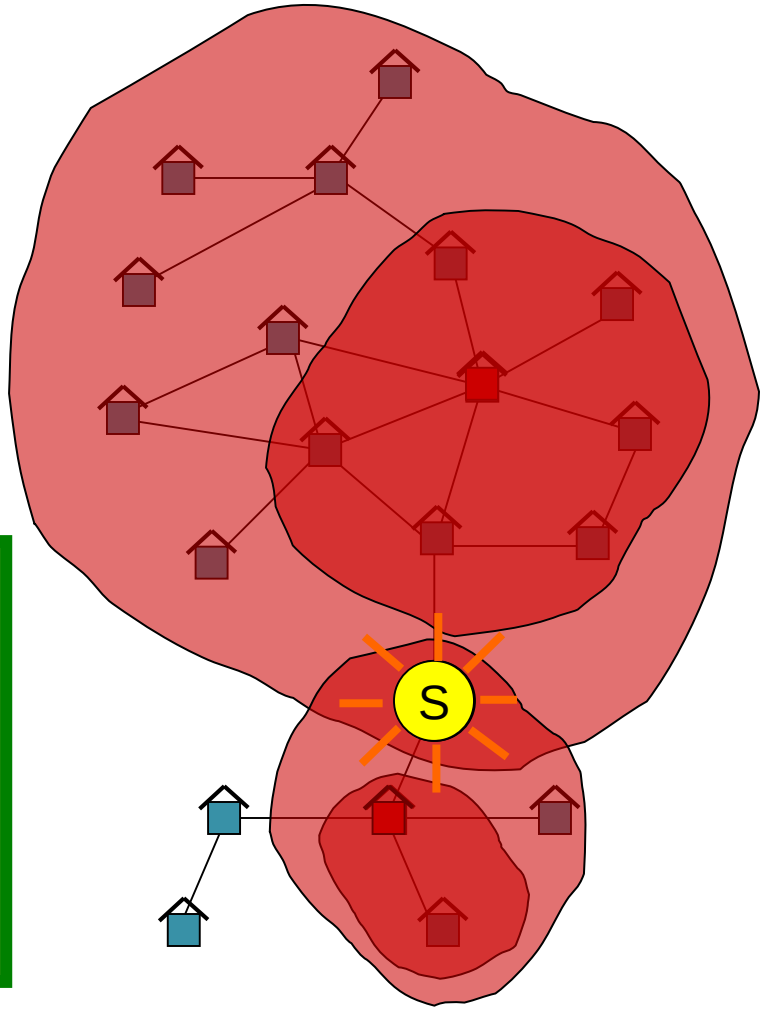
- Initially some nodes are active
- Active nodes spread their influence on the other nodes, and so on …



Scenario 1: Water network

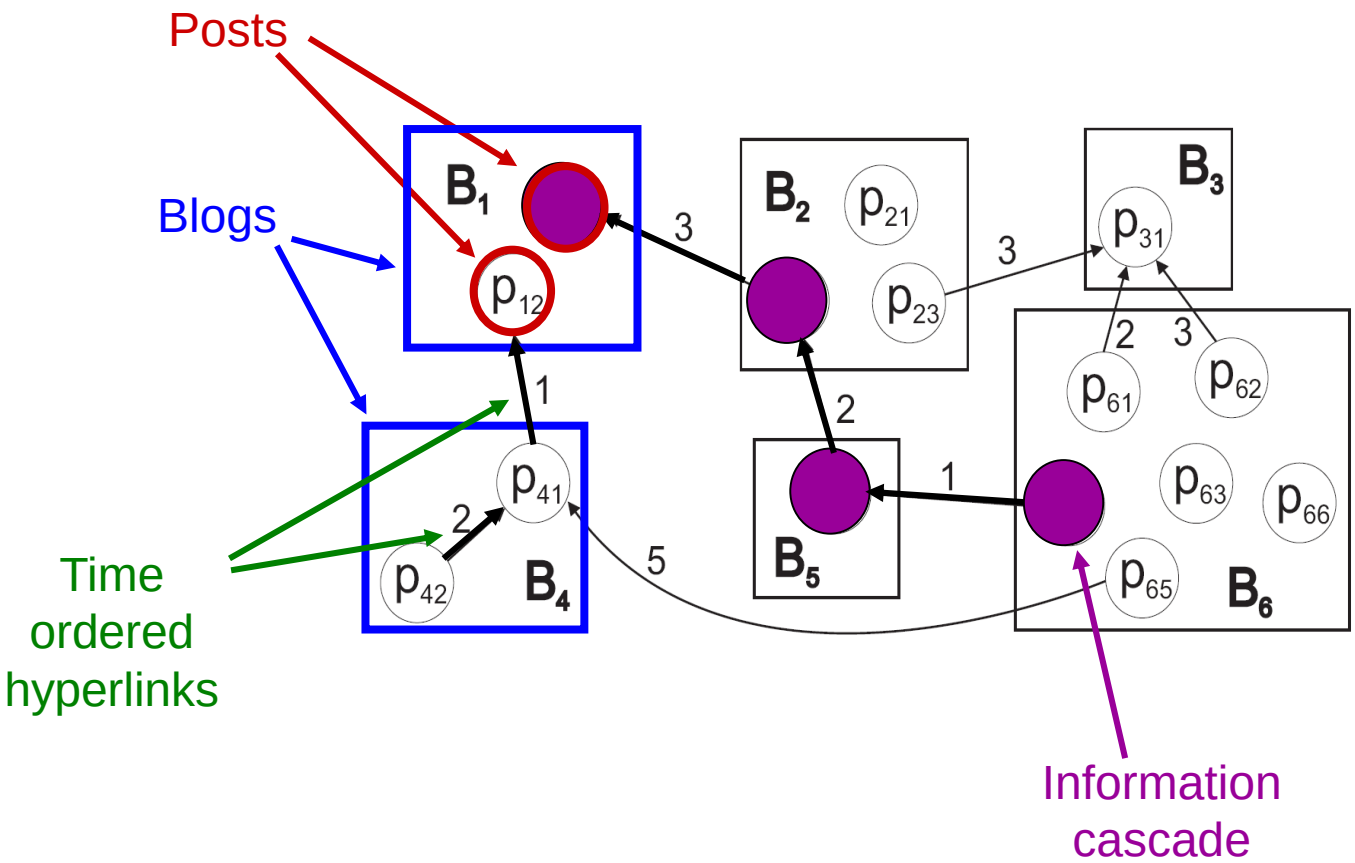
- Given a real city water distribution network
- And data on how contaminants spread in the network
- Problem posed by *US Environmental Protection Agency*

On which nodes should we place **sensors** to **efficiently** detect all the possible contaminations?



Scenario 2: Cascades in blogs

Which blogs should one read to **detect cascades** as **effectively** as possible?



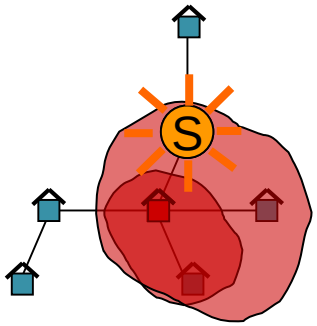
General problem

- Given a dynamic process spreading over the network
- We want to select a set of nodes to detect the process effectively

- Many other applications:
  - Epidemics
  - Influence propagation
  - Network security

Problem setting

- Given a graph $G(V,E)$
- and a budget B for sensors
- and data on how contaminations spread over the network:
  - for each contamination i we know the time $T(i, u)$ when it contaminated node u
- Select a subset of nodes A that maximize the expected reward



$$\max_{\mathcal{A} \subseteq \mathcal{V}} R(\mathcal{A}) \equiv \sum_i P(i) \underbrace{R_i(T(i, \mathcal{A}))}_{\text{Reward for detecting contamination } i}$$

subject to $cost(A) < B$

Two parts to the problem

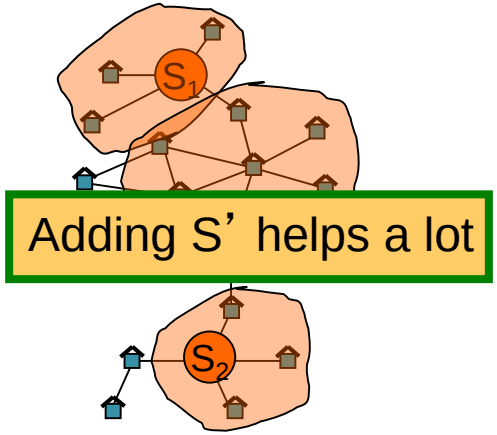
- Reward, e.g.:
  - 1) Minimize time to detection
  - 2) Maximize number of detected propagations
  - 3) Minimize number of infected people

- Cost (location dependent):
  - Reading big blogs is more time consuming
  - Placing a sensor in a remote location is expensive

Solving the problem

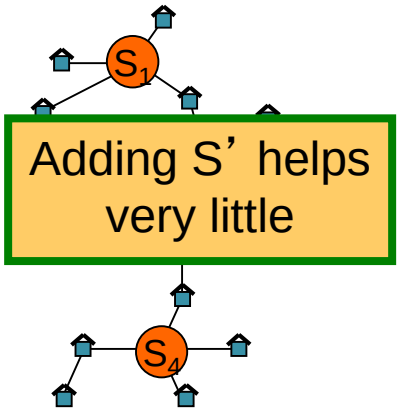
- Solving the problem exactly is NP-hard

- Main observation:
  - objective functions are submodular, i.e. diminishing returns



Placement $A=\{S_1, S_2\}$

New sensor:



Placement $A=\{S_1, S_2, S_3, S_4\}$

Lazy forward optimization

- Exploiting submodularity, significantly reduce # influence spread evaluations
  - S_{t-1} – seed set selected after round $t-1$
  - v_t – selected as seed in round t: $S_t = S_{t-1} \cup \{v_t\}$
  - u is not a seed yet, u's marginal gain $MG(u|S_t) = \sigma(S_t \cup \{u\}) - \sigma(S_t)$
  - by submodularlity, $MG(u|S_t) \leq MG(u|S_{t-1})$
  - This implies, if $MG(u|S_{t-1}) \leq MG(v|S_t)$ for some node v, then no need to evaluate $MG(u|S_t)$ in round $t+1$.
  - Can be implemented efficiently using max-heap
    - **take the top of the heap, if it has MG for the current round, then it is the new seed;**
    - **else compute its MG, and re-heapify**
- Often, top element after round $k-1$ remains top in round k.
- Up to 700 X speedup

Leskovec J, Krause A, Guestrin C, Faloutsos C, VanBriesen J, Glance NS (2007) Cost-effective outbreak detection in networks. *Proc. KDD 2007*

Battle of the Water Sensor Networks

- Largest water distribution considered for sensor placement
  - Consisted of 21,000 nodes and 25,000 pipes (edges)
  - Diffusion based on the *Independent Cascade Model*
  - Objective functions to be optimized :
    - DT (detection time) : time passed from beginning of contamination until the detection by one of the selected nodes.
    - PA (population detection) : injection rate varies with the water demand at a particular node and a person who ingest contaminated amount of water becomes infected with a certain probability.
  - **Outcome : CELF –lazy greedy forward selection alg. of [Leskovec2007] outperformed all other heuristic approaches**

References

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Questions?