SMART CITIES AS CYBER-PHYSICAL SYSTEMS

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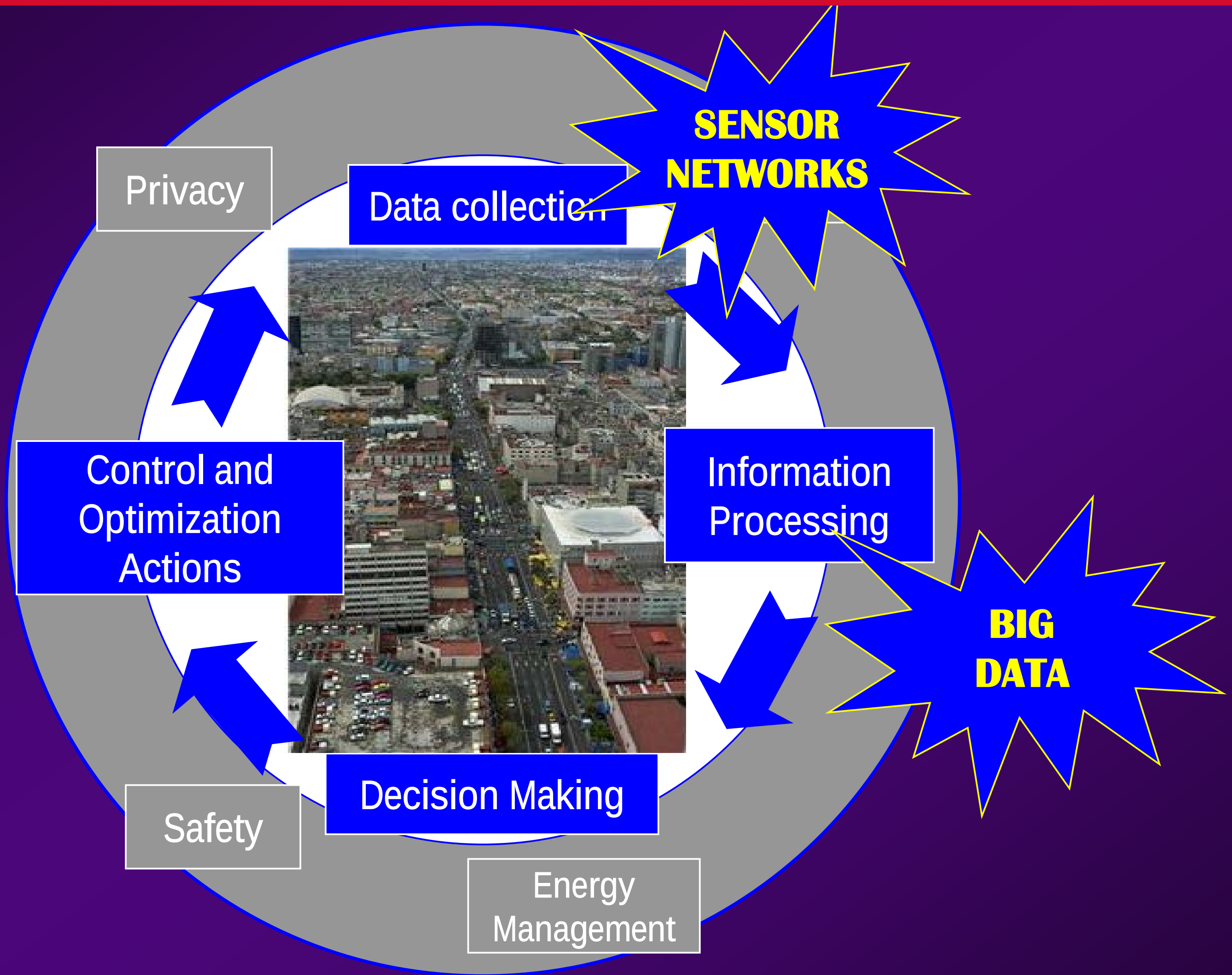
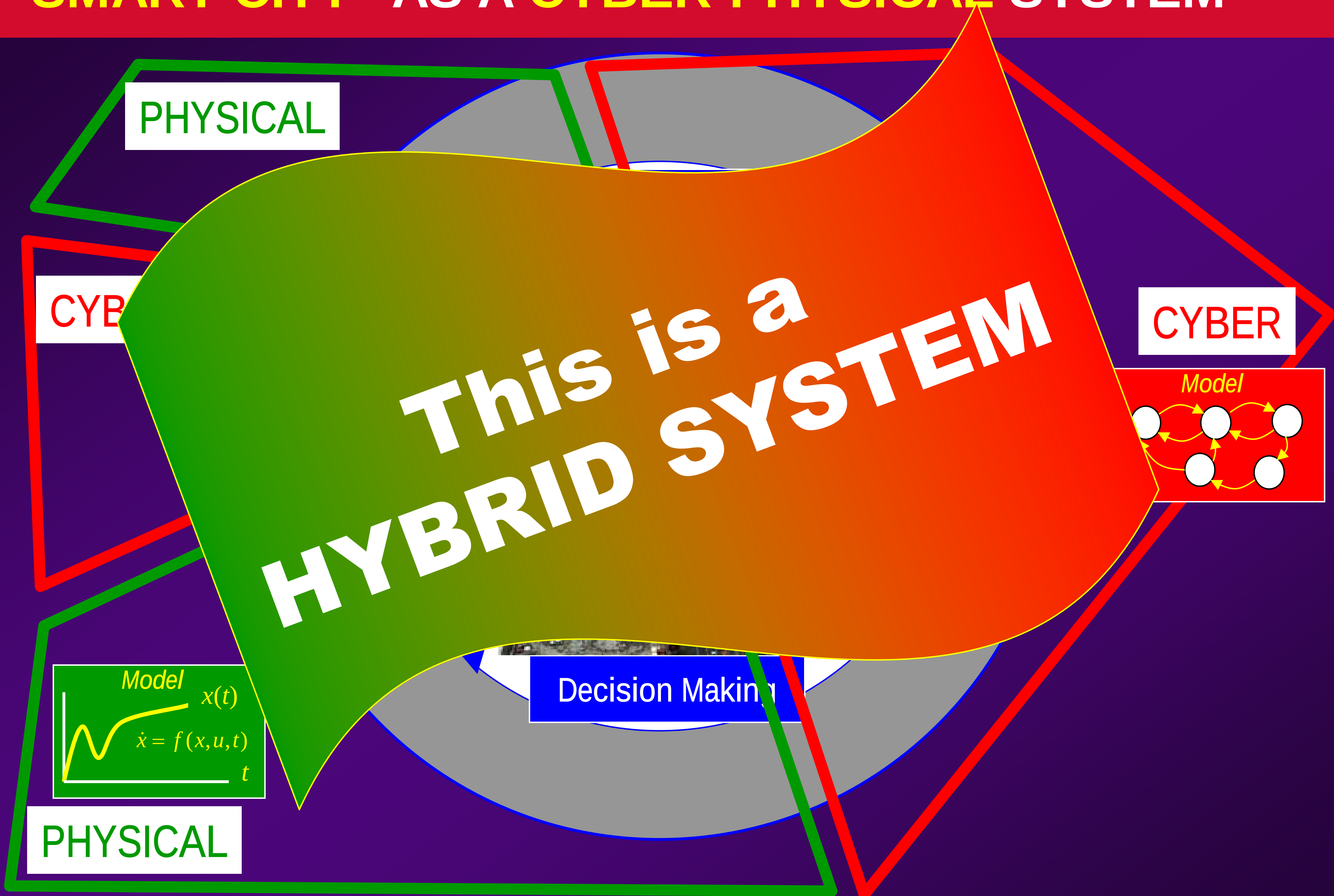
"SMART CITY" AS A CYBER-PHYSICAL SYSTEM



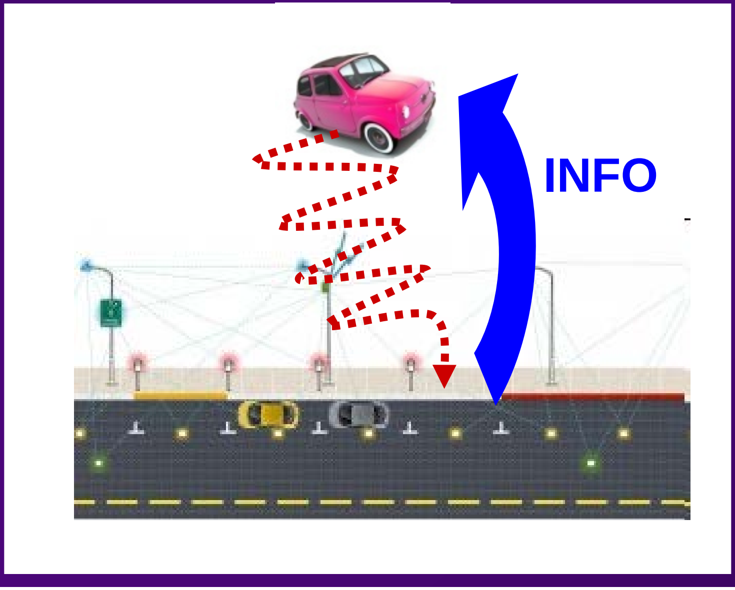
"SMART CITY" AS A CYBER-PHYSICAL SYSTEM



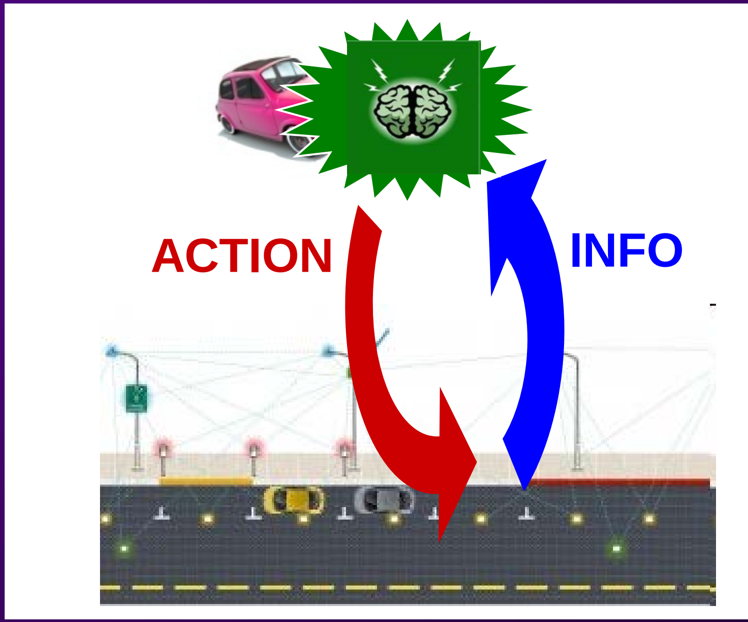
WHAT IS *REALLY* "SMART" ?

COLLECTING DATA IS NOT "SMART"

- JUST A NECESSARY STEP TO BEING "SMART"



PROCESSING DATA TO MAKE GOOD DECISIONS IS "SMART"



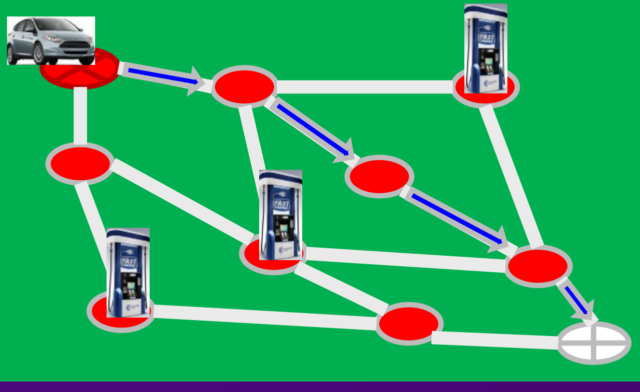
SMART CITY PROJECTS - *URBAN MOBILITY*

SMART PARKING

2011 IBM/IEEE Smarter Planet Challenge prize

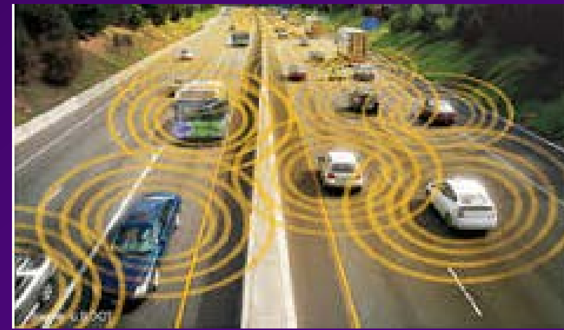
Finds optimal parking space for driver
+ reserves it

ELECTRIC VEHICLE (EV) ROUTING AND RECHARGING



Optimally routes EVs to minimize travel times
+ finds optimal charging station + reserves it

SMART CITY PROJECTS - *URBAN MOBILITY*



TRAFFIC CONTROL

Exploit “connected vehicles” technology:
from (selfish) “driver optimal” to
(social) “system optimal” traffic control

TRAFFIC LIGHT CONTROL

Real-time, data-driven dynamic traffic light control:

- Alleviate congestion
- Reduce pollution and fuel waste

SMART CITY PROJECTS - *URBAN MOBILITY*

STREET BUMP

2014 IBM/IEEE Smarter Planet Challenge prize

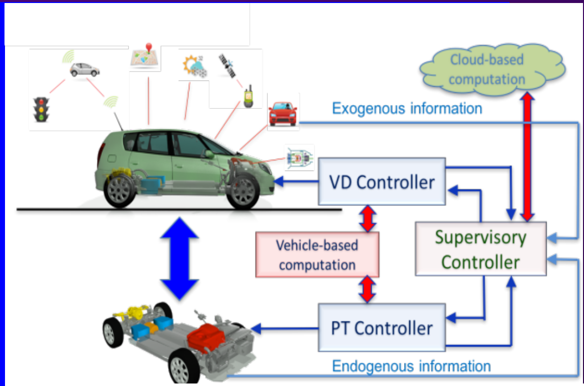
Detect roadway "bumps" + classify them + prioritize and dispatch crews

Used in Boston

SMART AUTONOMOUS CARS

NEXTCAR project :

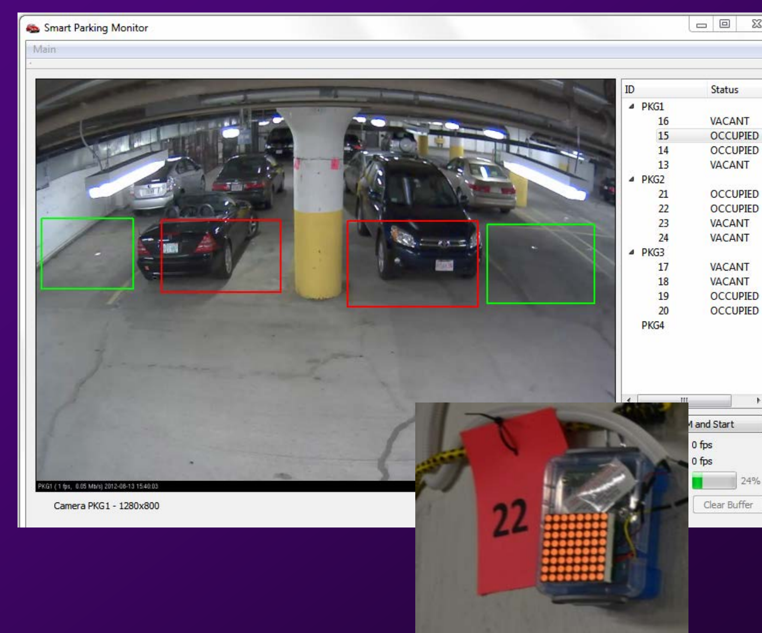
Self-driving autonomous cars for minimizing energy consumption: integrate *Vehicle Dynamics* with *Powertrain Control*



Vehicle control architecture concept

SMART PARKING

iPhone app



SMART PARKING

30% *of vehicles on the road in the downtowns of major cities are cruising for a parking spot. It takes the average driver* **7.8** *minutes to find a parking spot in the downtown core of a major city.*

R. Arnott, T.Rave, R.Schob, *Alleviating Urban Traffic Congestion.* 2005

GUIDANCE-BASED PARKING – DRAWBACKS…

Drivers:

- May not find a vacant space
- May miss better space
- Processing info while driving

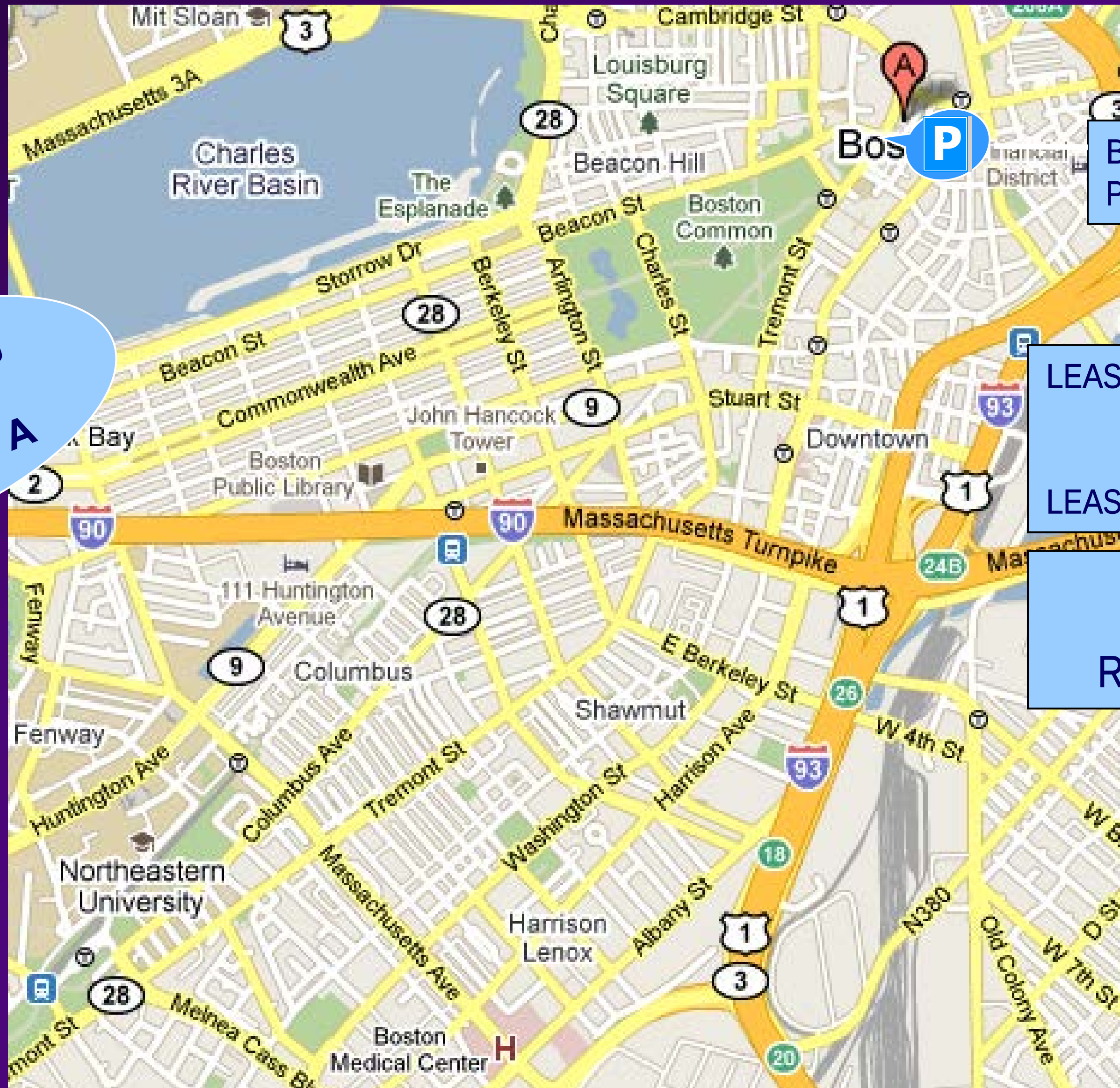
City:

- Imbalanced parking utilization
- May create ADDED CONGESTION (as multiple drivers converge to where a space exists)

Searching for parking $\Rightarrow$ Competing for parking

SMART PARKING

Find best parking spot for DESTINATION A



BEST PARKING SPOT

LEAST DISTANCE from A

+

LEAST COST

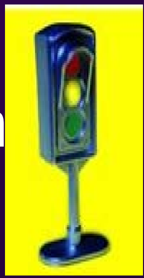
+

RESERVE IT

[Geng and Cassandras, *IEEE Trans. on Intelligent Transportation Systems*, 2013]

SMART PARKING – IMPLEMENTATION

- Parking space availability detection ➡
  - Standard sensors (e.g., magnetic, cameras)
  - Wireless sensor networking
- Vehicle localization ➡
  - GPS
- System-Driver communication ➡
  - Smartphone
  - Vehicle navigation system
- Parking reservation ➡
  - Red/Green/Yellow light system



SIMULATION CASE STUDY

On-street parking spaces

Off-street parking spaces

Points of interest

KEY CONCLUSIONS

1. 10-20% higher parking utilization
   $\Rightarrow$ HIGHER REVENUE,
   LOWER CONGESTION

2. % drivers searching for parking (wandering) < 2%
   $\Rightarrow$ HIGHER REVENUE,
   LOWER CONGESTION

3. 50% reduction in parking time under heavy traffic
   $\Rightarrow$ LOWER CONGESTION,
   LESS FUEL,
   DRIVER COMFORT

STREET BUMP: DETECTING "BUMPS" THROUGH SMARTPHONES + DATA ANALYTICS

iPhone app

2014 IBM/IEEE Smarter Planet Challenge prize

STREET BUMP – PROCESSING "BIG DATA"

- Detect obstacles using iPhone accelerometer and GPS
  ⇒ no infrastructure needed

- Send to central server through Street Bump app

- Process data to classify obstacles:

  Anomaly detection and clustering algorithms,
  similar to cybersecurity problems

- Detect "actionable" obstacles

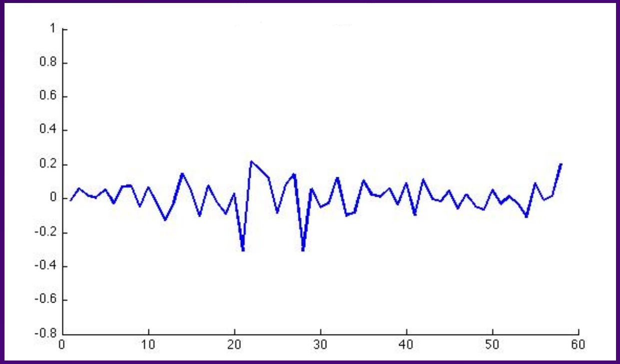
- Prioritize and dispatch Smart City crews to fix problems:

  DATA-DRIVEN DYNAMIC RESOURCE ALLOCATION

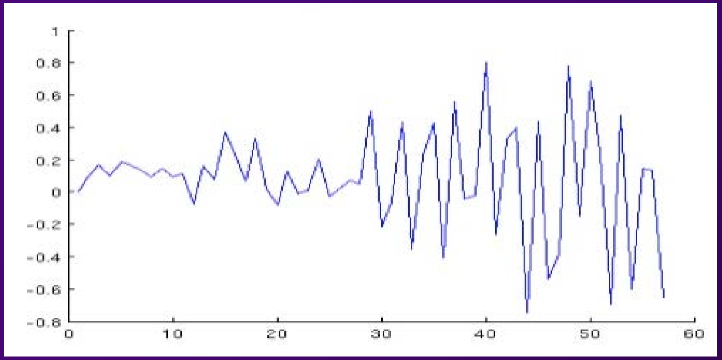
STREET BUMP – PROCESSING “BIG DATA”

Methodologies used:

- Anomaly detection, Machine Learning algorithms
- Bump signal signature analysis: REGULARITY METRIC
- Bump signal randomness content: ENTROPY METRIC



NON-ACTIONABLE
(Flat Casting)



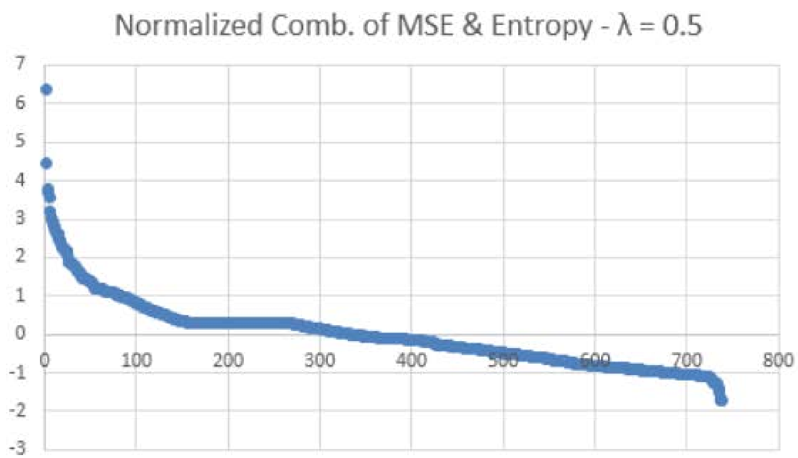
ACTIONABLE
(Pothole)

STREET BUMP – ANOMALY INDEX RANKED LIST

$$AI = 0.5MSE + 0.5H(x)$$

TOP-10 ACTIONABLE OBSTACLES

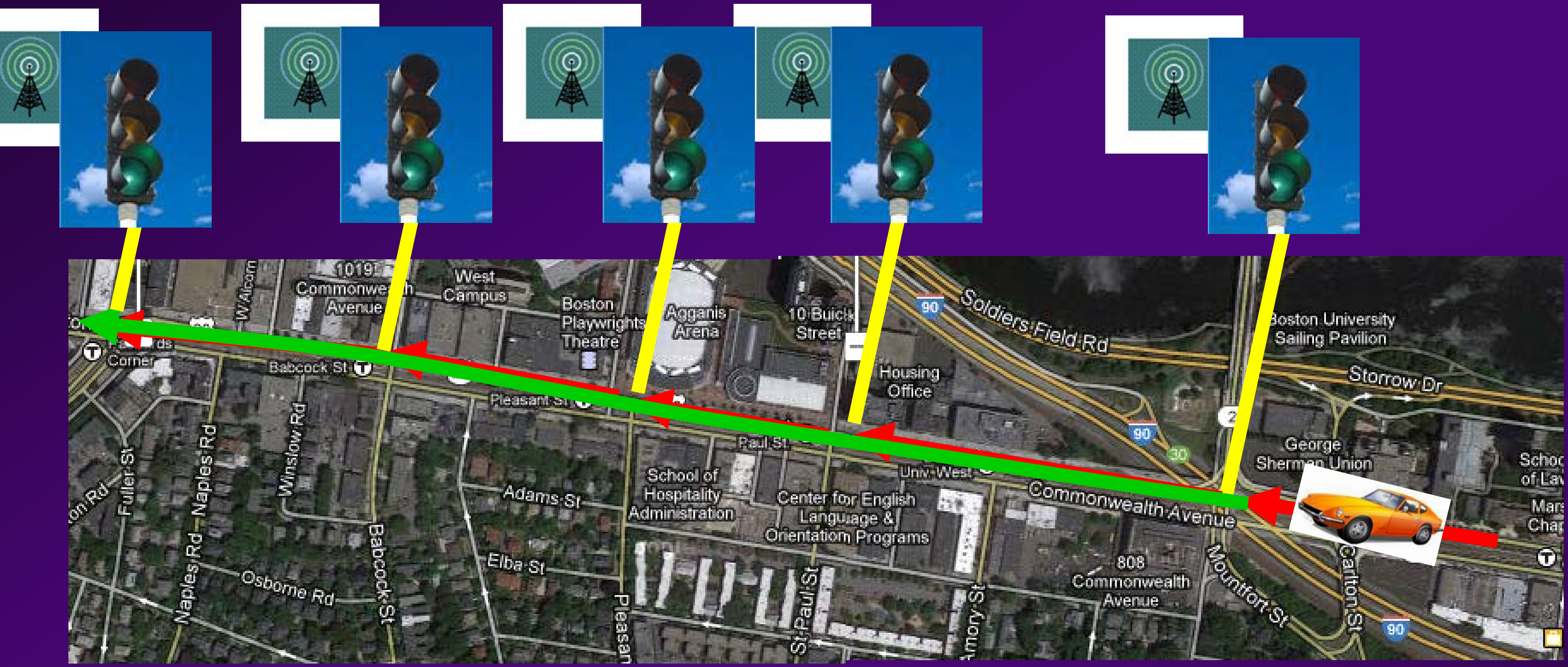
- $\lambda = 0.5$
- Truly actionable (T): 88/100 (88%)
- False Alarm (F): 12%



Categories	1 = Non-actionable	Comb. of MSE&Entropy
'Pot Hole'	2	6.358133291
'Sunk Casting (Immediate repair)'	2	4.458249603
'Pothole'	2	3.781396384
'Cracking Around Casting (Pothole)'	2	3.696543324
'Bad Utility Patch (permanent)'	2	3.553264957
'Pothole'	2	3.209940023
'Pothole'	2	3.035801435
'Bad Utility Patch (permanent)'	2	2.963345039
'Flat Casting'	1	2.928413599
'Pothole'	2	2.83604503
'Bad Utility Patch (permanent)'	2	2.783582864
'Sunk Casting (immediate repair)'	2	2.726196475
'Catch Basin (repair)'	2	2.626632962
'Pothole'	2	2.626487835
'Sunk Casting (repair)'	2	2.496122077
'Bad Utility Patch (permanent)'	2	2.441951962
'Pothole'	2	2.393910452
'Sunk Casting (immediate repair)'	2	2.302992173
'Sunk Casting (repair)'	2	2.271229115
'Pot Hole'	2	2.253794862
'Sunk Casting (repair)'	2	2.225175587
'Sunk Casting (immediate repair)'	2	2.204039646
'Cracking Around Casting (pothole)'	2	2.186933029
'Pothole'	2	2.169196119
'Bad Utility Patch (temporary)'	2	2.096893702
'Pothole'	2	1.961382389
'Sunk Casting (repair)'	2	1.876441708
'Flat Casting'	1	1.855250669
'Pot Hole (no repair)'	1	1.83324128
'Bad Utility Patch (permanent)'	2	1.825949708
'Sunk Casting (Repair)'	2	1.815833626
'Pothole'	2	1.772191028
'Sunk Casting (repair)'	2	1.766306302
'Flat Casting'	1	1.747079501
'Sunk Casting (repair)'	2	1.681360281
'Sunk Casting (immediate repair)'	2	1.651942764
'Raised Casting (repair)'	2	1.618505807
'Pothole'	2	1.574023242
'Sunk Casting (immediate repair)'	2	1.574015672
'Pothole'	2	1.497205598
'Pot Hole'	2	1.484528469
'Pothole'	2	1.469825022
'Catch Basin (repair)'	2	1.462558728
'Sunk Casting (repair)'	2	1.454257109
'Pothole'	2	1.453174152
'Flat Casting'	1	1.422754809
'Sunk Casting (repair)'	2	1.417971776
'Pothole'	2	1.402428087
'Catch Basin (repair)'	2	1.37466431

ADAPTIVE TRAFFIC LIGHT CONTROL

NETWORK-WIDE TRAFFIC LIGHT CONTROL



- Automatically adapt red/green light cycles based on observed data
- Predict and alleviate congestion over entire urban network
- Reduce waiting times, congestion
- Reduce pollution and fuel waste

TRAFFIC CONTROL

The BU Bridge mess, Boston, MA (simulation using VISSIM)

... EVEN IF WE KNOW THE ACHIEVABLE OPTIMUM IN A TRAFFIC NETWORK ???

Because:

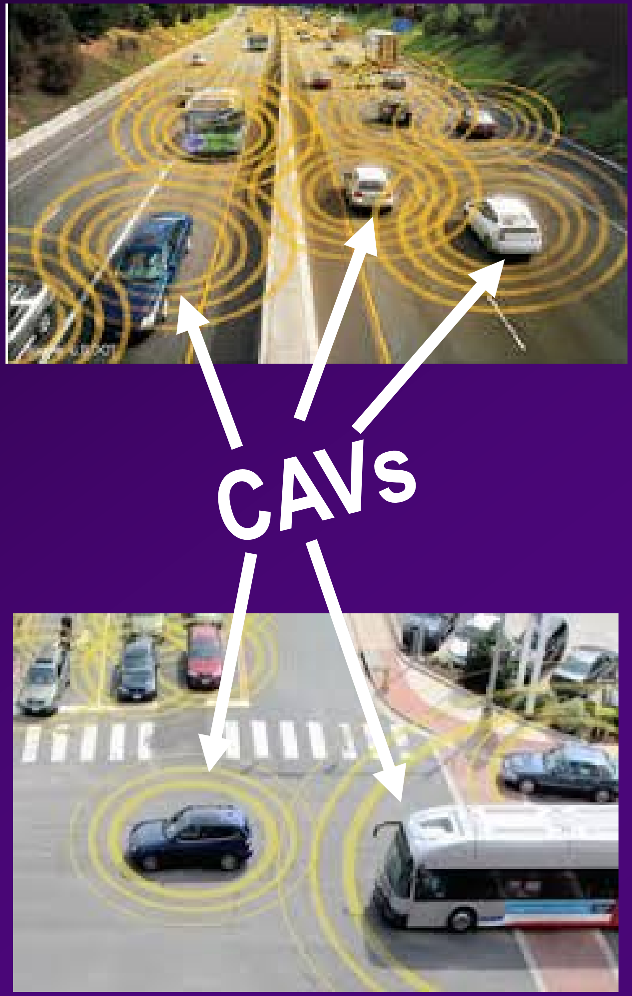
- Not enough controls (traffic lights, tolls, speed fines)

  → No chance to unleash the power of feedback!

- Not knowing other drivers' behavior leads to poor decisions (a simple game-theoretic fact)

  → Drivers seek individual (selfish) optimum, not system-wide (social) optimum } *PRICE OF ANARCHY* (POA)

GAME-CHANGING OPPORTUNITY:
CONNECTED AUTONOMOUS VEHICLES (CAVs)



FROM (SELFISH) "DRIVER OPTIMAL"
TO (SOCIAL) "SYSTEM OPTIMAL"
TRAFFIC CONTROL

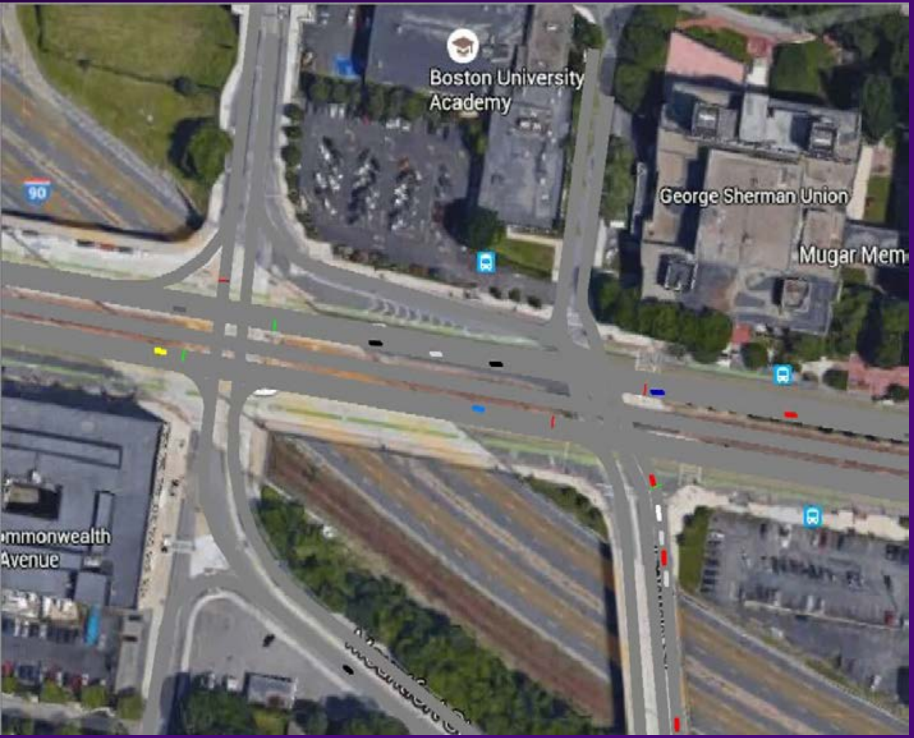
THE "INTERNET OF CARS"

NO TRAFFIC LIGHTS, NEVER STOP…

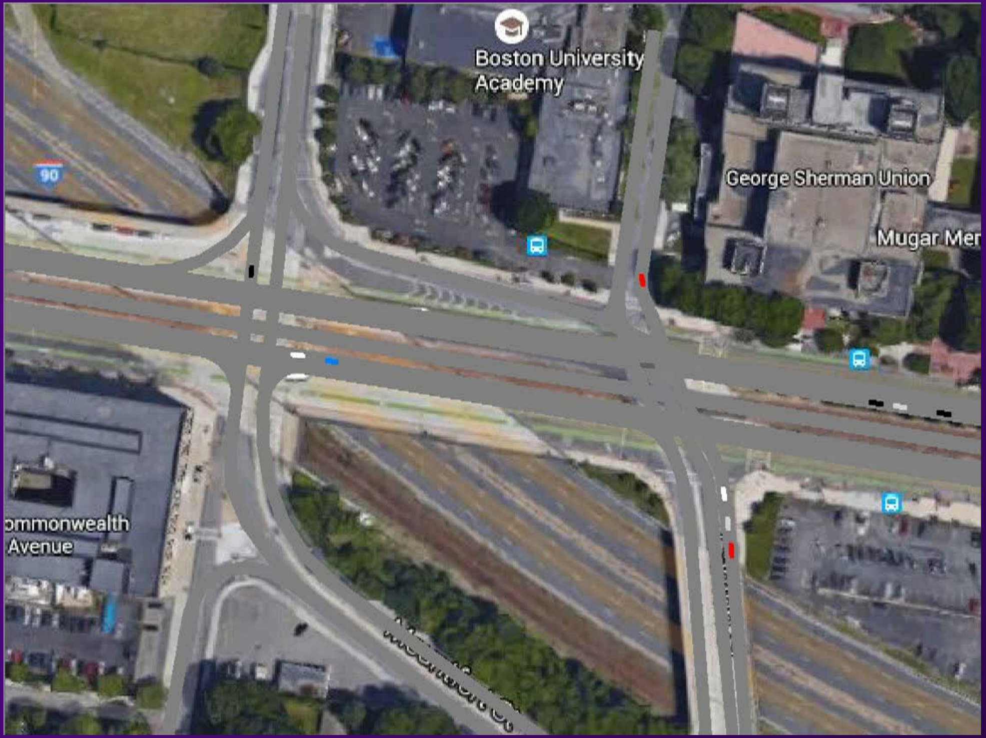
[Zhang et al, *Proceedings of the IEEE*, Special Issue on Smart Cities, 2018]

WHO NEEDS TRAFFIC LIGHTS?

With traffic lights



With decentralized control of CAVs



One of the worst-designed double intersections ever…

(BU Bridge – Commonwealth Ave, Boston, MA)

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WHERE DISCOVERIES BEGIN

U.S. AIR FORCE

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arpa-e
CHANGING WHAT'S POSSIBLE

City of Boston.gov

MathWorks

BOSCH
Invented for life

Schneider Electric

Honeywell
THE POWER OF CONNECTED

Thank you