



Internet of Things

Everything will be connected

Introduction
18-738 Sports Technology

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India



Professor, Carnegie Mellon



CEO & Founder, YinzCam, Inc.



Zambia



PhD, UC Santa Barbara
CTO, Eternal Systems



Director, Intel Labs
Pittsburgh



Director, Intel Science
& Tech Center in
Embedded Computing

My Background

◆ At Carnegie Mellon

- ◆ Faculty in ECE since 2001
- ◆ 18-349 instructor since 2001
- ◆ 18-549 instructor since 2006

◆ Industry experience

- ◆ CEO and Founder, YinzCam, Inc.
- ◆ Founded 2 other startups
- ◆ Director, Intel Labs Pittsburgh

◆ Passionate about sports

- ◆ All aspects
- ◆ Bringing technology to sports
- ◆ Bringing sports into the classroom





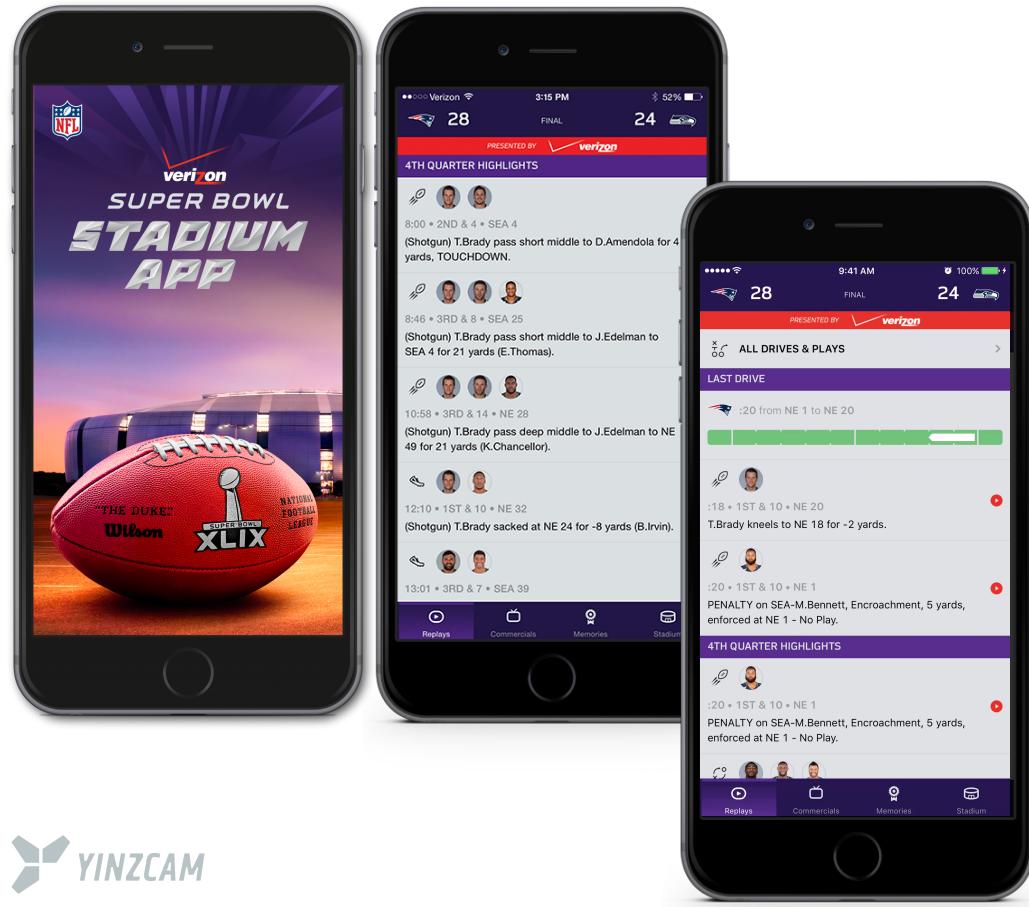
In the beginning



The birth of a company



Innovations: At Super Bowl XLIX



United Center - Bulls

Clock offset: -2

Default feed: 1

Highlight	Verified	time	Auto	Manual	Clock	Period
	Yes	Apr 27 06:05:46PM	complete	complete	00:19	OT3
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Feed 1 Feed 2 Feed 3 use auto use manual show auto show manual

enabled

	Yes	Apr 27 06:01:15PM	complete	complete	00:21	OT3	[BKN 134-137] Lopez Layup Shot: Made (26 PTS)	Show
	No	Apr 27 05:58:50PM	complete	na	00:32	OT3	[CHI 137-132] Mohammed Jump Shot: Made (7 PTS) Assist: Hinrich (14 AST)	Show
	No	Apr 27 05:54:20PM	complete	na	02:35	OT3	[CHI 135-130] Deng Jump Shot: Made (15 PTS)	Show



Live Cameras | Highlights C

Historical Previous Current

Presented by AT&T

3RD QUARTER HIGHLIGHTS

- Belinelli 3pt Shot (17 PTS) 4:26 3RD [CHI 68-69] Assist: Robinson (2 AST)
- Butler Driving Slam Dunk Shot (13 PTS) 5:19 3RD [CHI 65-67] Assist: Noah (3 AST)
- Boozer Slam Dunk Shot (10 PTS) 9:43 3RD [CHI 59-65] Assist: Butler (6 AST)
- Robinson 3pt Shot (12 PTS) 11:48 3RD [CHI 57-60] Assist: Belinelli (7 AST)

2ND QUARTER HIGHLIGHTS

- Belinelli 3pt Shot (14 PTS) :11 2ND [CHI 54-60] Assist: Teague (1 AST)
- Williams 3pt Shot (11 PTS)

Automation for mobile-highlight creation

Technical Challenges

Broadcast rights. Game footage can never leave the building.

Content rights. Needed for some kinds of content.

Minimal manual intervention. Cannot afford to have humans in the loop, especially for time-sensitive consumption of media.

Scalability. Need to be able to handle dynamic load.

Scalable operations. Need to be able to handle multiple teams and facilities at the same time.

Latency. Need to provide the best quality-of-service for specific kinds of content, e.g., replays



The Roster

NFL Clubs	NBA Teams	Leagues	La Liga Clubs (Spain)	AFL Clubs (Australia)	NCAA Colleges
Pittsburgh Steelers	Phoenix Suns	La Liga (Spain)	D. Alavés	Sydney Swans	Texas A&M University
Buffalo Bills	Washington Wizards	NRL Live (Australia)	Albacete Balompié	Geelong Cats	Kansas University
New England Patriots	Charlotte Hornets	Super Netball (Australia)	AD Alcorcón	Hawthorn	Baylor University
New York Giants	Chicago Bulls	NBL (Australia)	UD Almería	GWS Giants	University of Wisconsin
New York Jets	Golden State Warriors	AFL Women's (Australia)	Cádiz CF	Adelaide Crows	Notre Dame University
Baltimore Ravens	Houston Rockets	AFL Under-18 (Australia)	Cultural	West Coast Eagles	
Cincinnati Bengals	Memphis Grizzlies	All Blacks / NZR (NZ)	SD Eibar	Western Bulldogs	
Houston Texans	Milwaukee Bucks	New Zealand Cricket (NZ)	Elche	North Melbourne	
Tennessee Titans	New Orleans Pelicans	AFL Live for Windows	Getafe CF	St. Kilda	NHL Clubs
Denver Broncos	Oklahoma City Thunder	NBA G-League	SD Huesca	Port Adelaide	Pittsburgh Penguins
Kansas City Chiefs	Philadelphia 76ers	Jr. NBA (kids' app)	CD Lugo	Melbourne	Buffalo Sabres
Dallas Cowboys	San Antonio Spurs	USA Basketball	Mallorca	Collingwood	Toronto MapleLeafs
Philadelphia Eagles	Cleveland Cavaliers	NBA Moji	Nàstic de Tarragona	Richmond	
Chicago Bears	New York Knicks	NBA2K (NBA e-League)	Numancia	Carlton	
Seattle Seahawks	Atlanta Hawks		CA Osasuna	Gold Coast Suns	CFL Clubs (Canadian football)
Detroit Lions	Indiana Pacers	Venues	Real Oviedo	Fremantle	Calgary Stampeders
Green Bay Packers	Denver Nuggets	United Center	Rayo Vallecano	Brisbane Lions	Saskatchewan Roughriders
New Orleans Saints	Brooklyn Nets	Gillette Stadium	Real Sporting de Gijón	Essendon	Winnipeg BlueBombers
Minnesota Vikings	Los Angeles Lakers	Verizon Center	CD Tenerife		
Carolina Panthers	Los Angeles Clippers	Patriot Center	Real Valladolid	NZR (New Zealand)	
Tampa Bay Buccaneers	Toronto Raptors	Sports Authority Field	Real Zaragoza	All Blacks	
Arizona Cardinals	Boston Celtics	Toyota Center		Vodafone Warriors	
St. Louis Rams		Soldier Field		New Zealand Cricket	
Oakland Raiders	WNBA Teams	CenturyLink Field	U.K. Clubs		AHL Clubs
Cleveland Browns	Phoenix Mercury	Barclays Center	Wolves FC	All Black	Lehigh Valley Phantoms
	Washington Mystics	Vodafone Stadium Live	Blackburn Rovers	Vodafone Warriors	Lake Erie Monsters
	New York Liberty	Madison Square Garden	Barnsley	New Zealand Cricket	
	Minnesota Lynx	Radio City Music Hall	Sunderland FC		
	Indiana Fever	Beacon Theater		Events	
	Dallas Wings	Scotiabank Arena		NFL Pro Bowl 2015	
	Las Vegas Aces			NFL Super Bowl XLIX	
	Connecticut Sun			NBA All-Star 2015	
	Chicago Sky			NRL Auckland Nines 2015	
				Big East Tournament 2015	
				Breeders Cup 2017	
				Indian Wells Tennis 2018	
			MLS Clubs		
			New England Revolution		
			Toronto FC		



180.38 billion

USER-ACTION RECORDS

34,241,601,697

PUSH NOTIFICATIONS

79,406,781

APP INSTALLS

8.92 petabytes

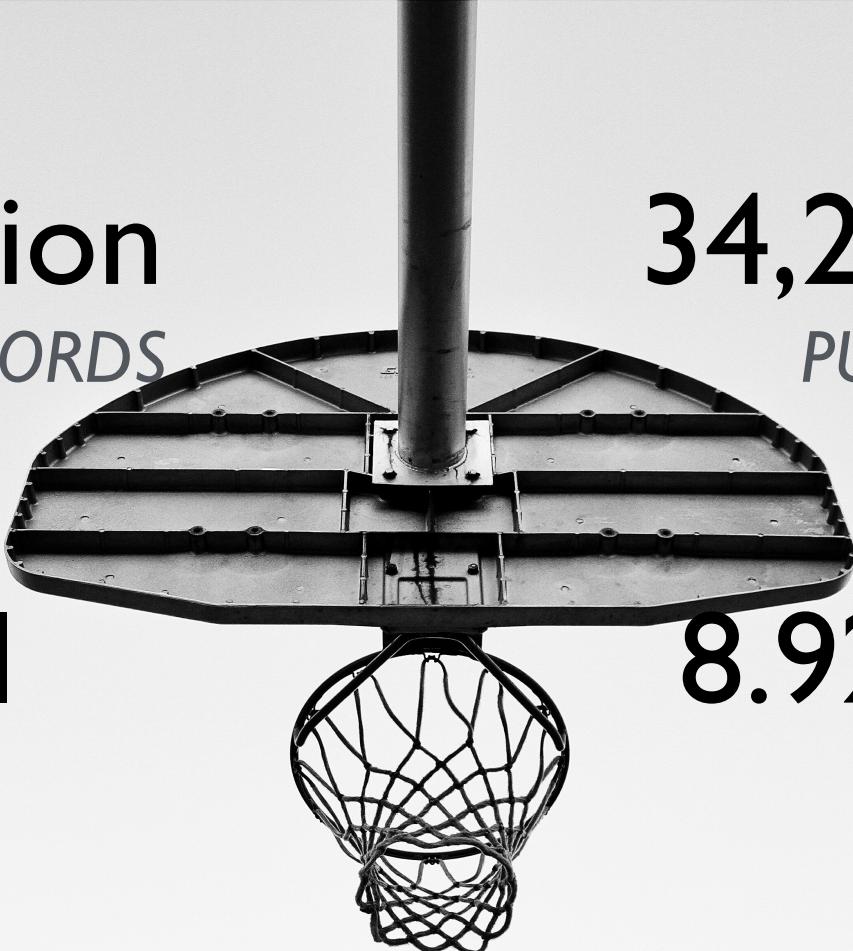
DATA SERVED

16,912,597,455

PAGE VIEWS

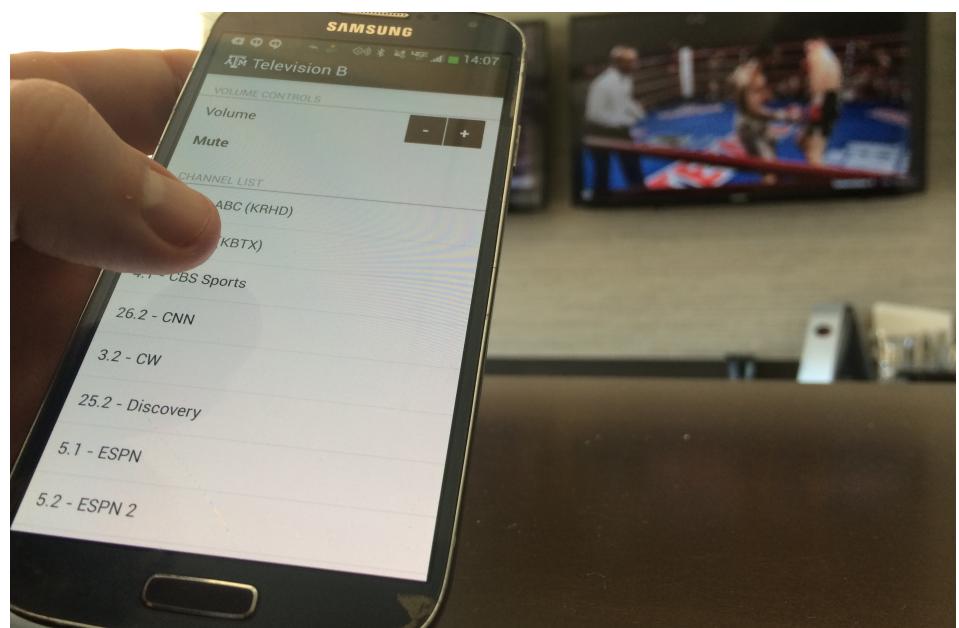
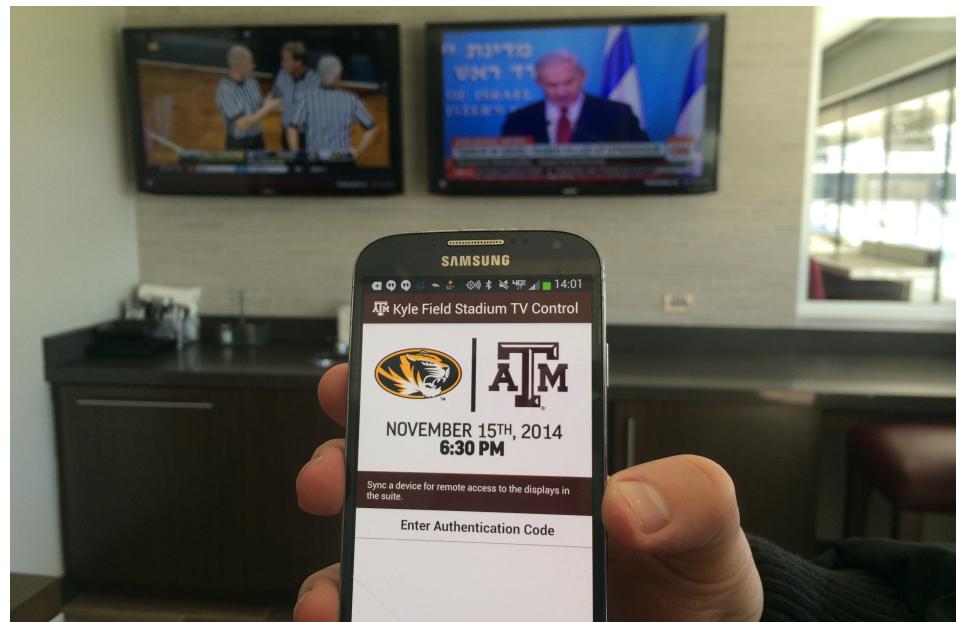
877,774,952,448s

TIME SPENT





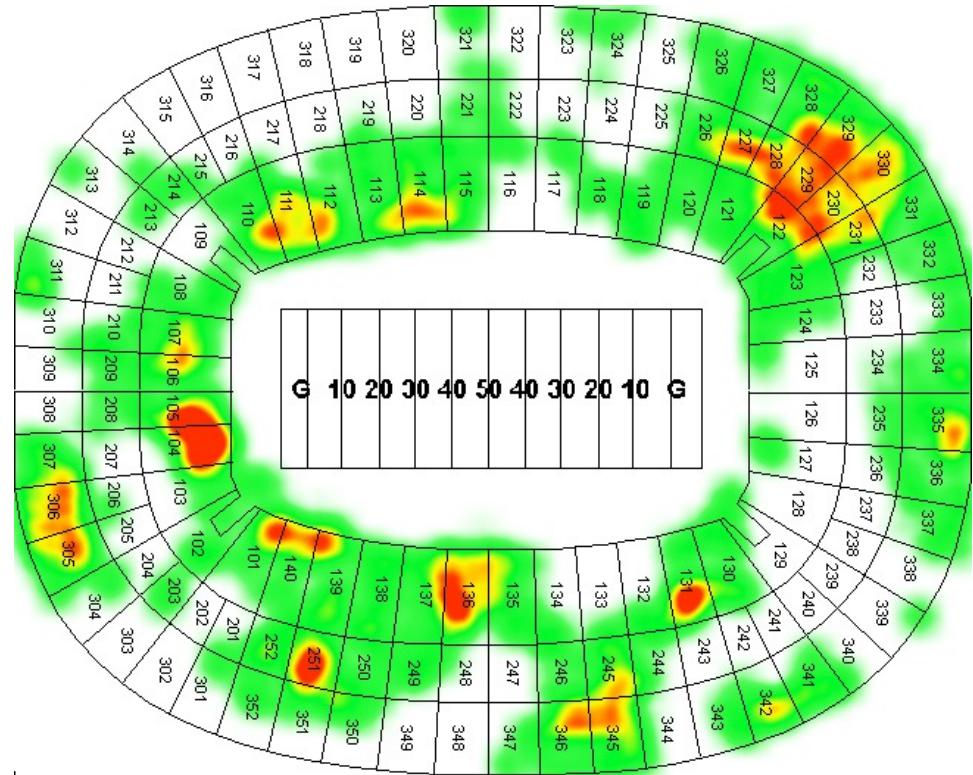
Adding wearable devices to the mix



Adding other display devices to the mix
Interfacing with televisions and set-top boxes

Innovations: Wireless Analytics

- **Wireless analytics package**
 - In-seat measurement tool in fans' hands
- **Can measure and report (in real-time)**
 - Signal strength
 - Number of instances of video buffering
 - Number of video interruptions
 - Number of uninterrupted-video sessions
 - Number of failed calls for content
 - Battery life
- **Why?**
 - Measure ROI on wireless investment
 - Shows quality of fan experience
 - Actionable data to improve wireless



Innovations: Edge Clouds

- **Wealth of devices**

- Number of mobile devices growing
- Each of them growing in computation
- Each of them growing in storage, memory

- **What if more devices = better infrastructure?**

- Crowd-source devices and their computation
- Run “edge clouds” out of devices alone
- No access to server infrastructure at all
- Can help alleviate bandwidth issues

- **Have experimented with edge-clouds**

- Initial results show great promise
- Experimentation with stadiums, stores
- *ACM MobiArch 2015 Best Paper Award*
- *ACM GPCE 2015 keynote*



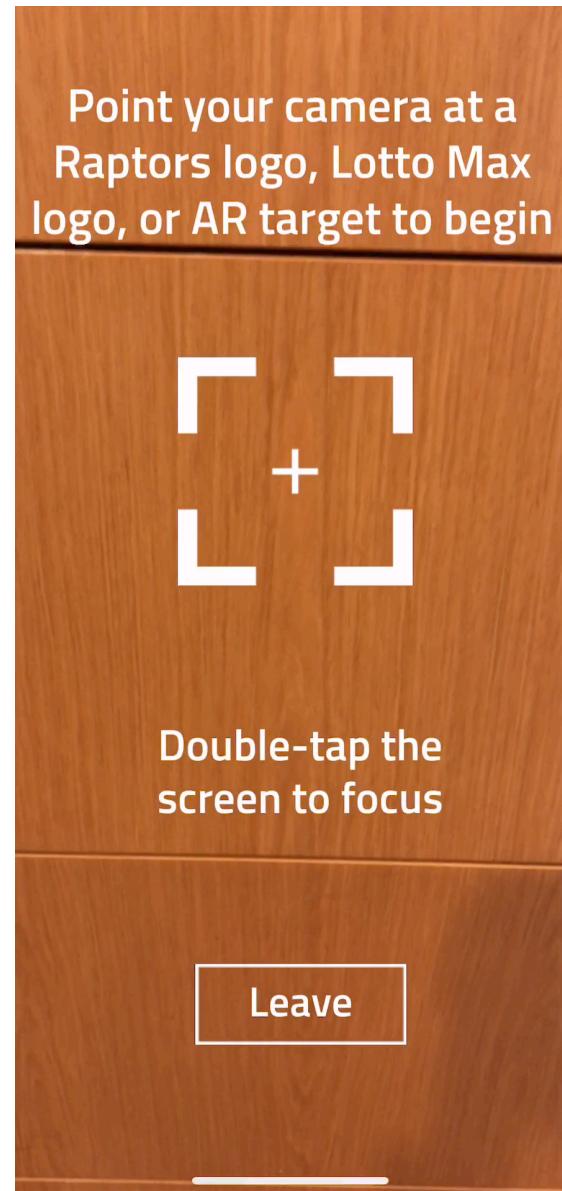
Augmented-Reality Work



Deep in The Q Done

17 Achievements

	You've Arrived!	10 PTS
	Congratulations! Your hot hand drained 10 baskets in a row. Be sure not to tou...	10 PTS
	Congratulations! Your hot hand drained 20 baskets in a row. Be sure not to tou...	10 PTS
	Achieve a streak of 30 baskets!	10 PTS
	Missed a handful of shots?	10 PTS
	Make Cleveland proud!	10 PTS
	Earn your first of 5 Cavaliers logos	10 PTS





POP-A-SHOT
THE VIRTUAL REIMAGINED FOR

SEARCH FOR & DOWNLOAD
DEEP IN THE Q



Player 1

3

Player 2

0

Shot Clock:

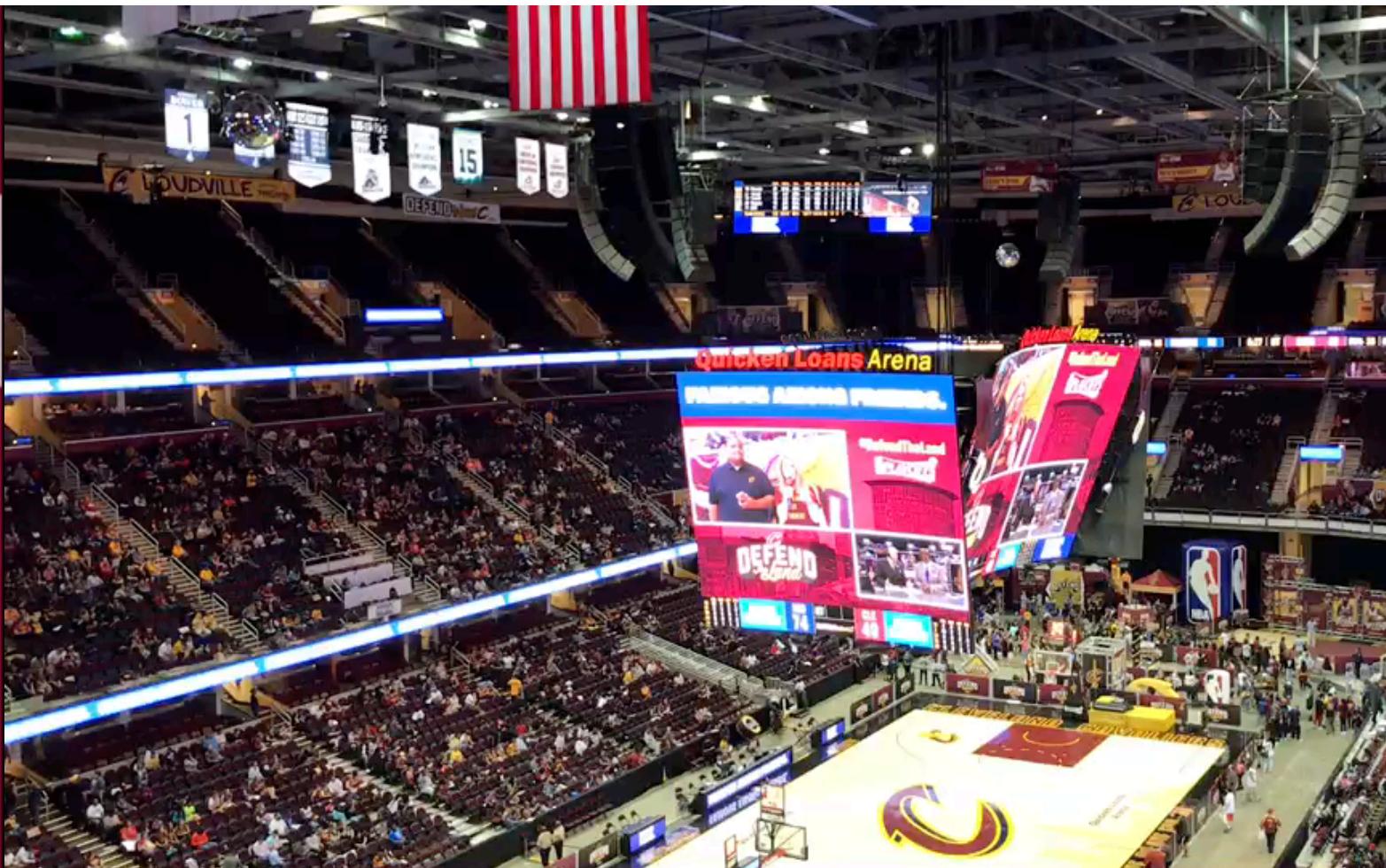
26



Example: Interactive In-Arena Game

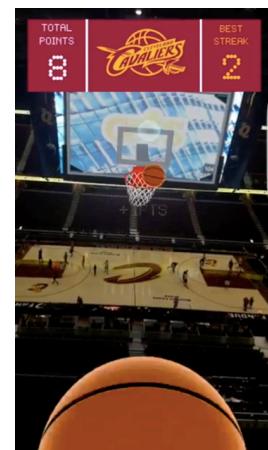


BE A BALLER AMONG
FRIENDS WITH DEEP IN
THE Q VIRTUAL HOOPS

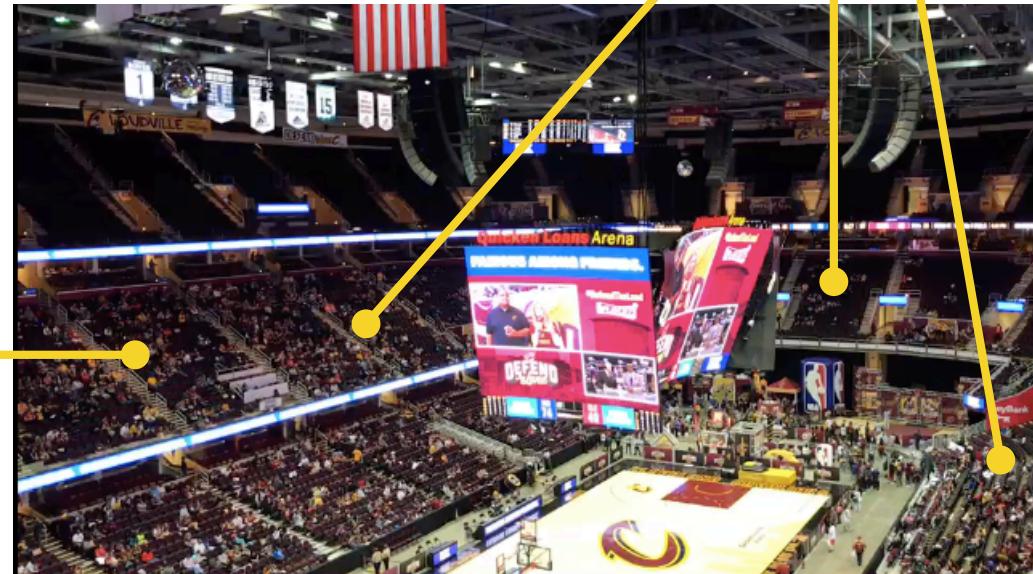




*Fans competing head-to-head
at a video wall*

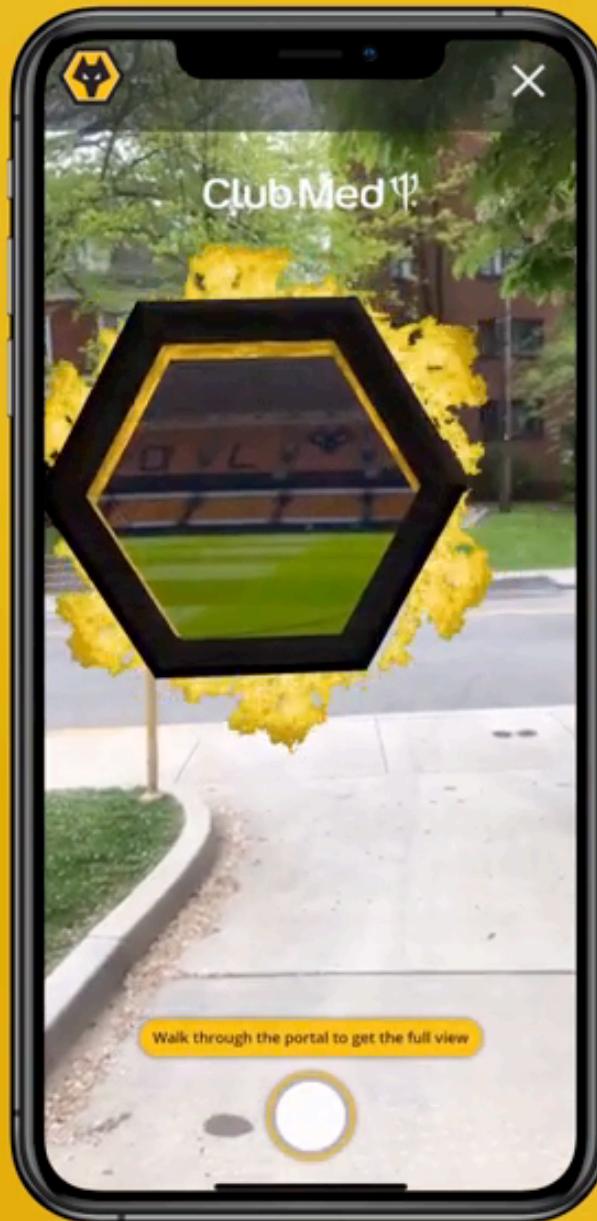


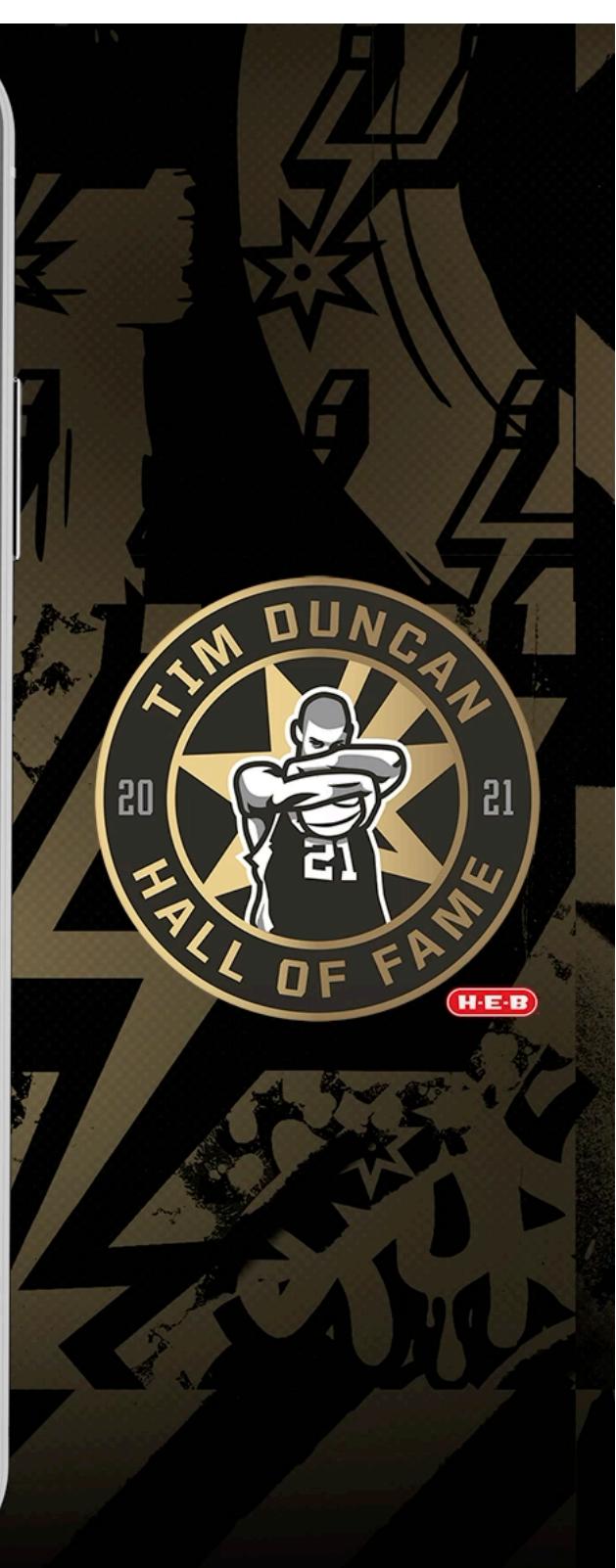
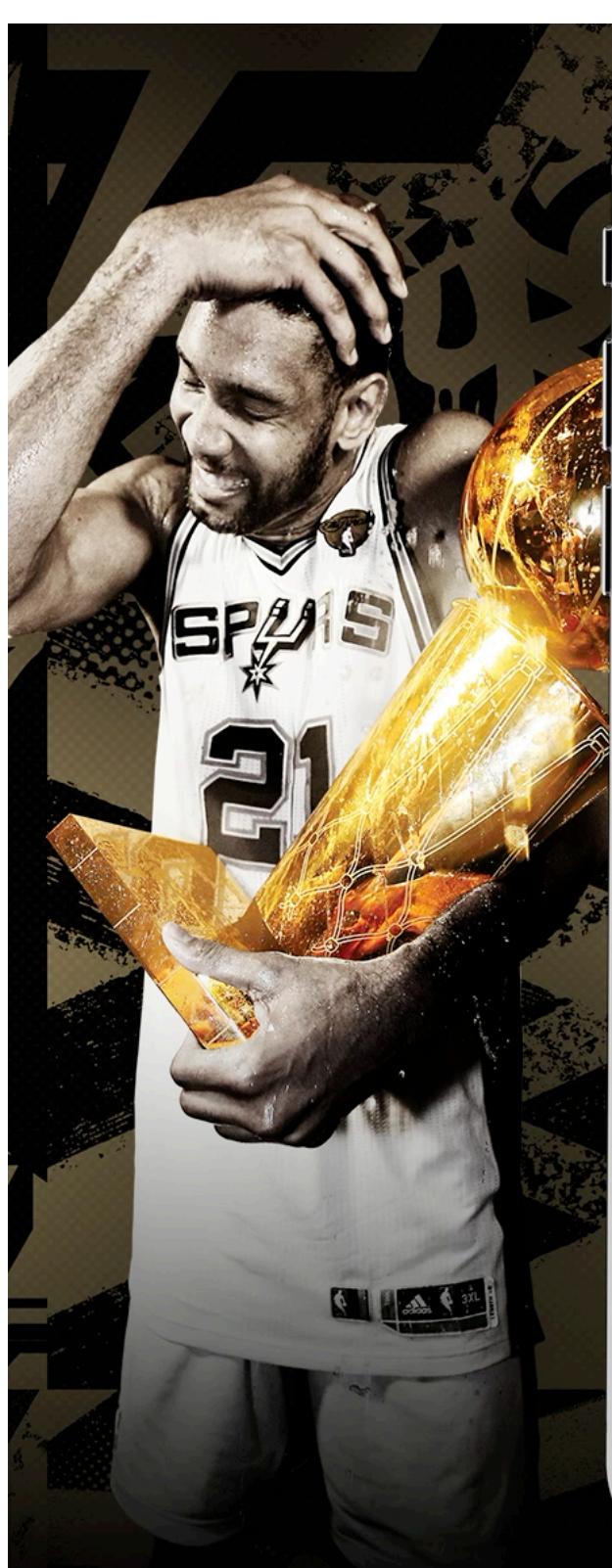
*Fan points and
shoots at the
video board*



*Fans competing
across sections
by pointing at
the videoboard*

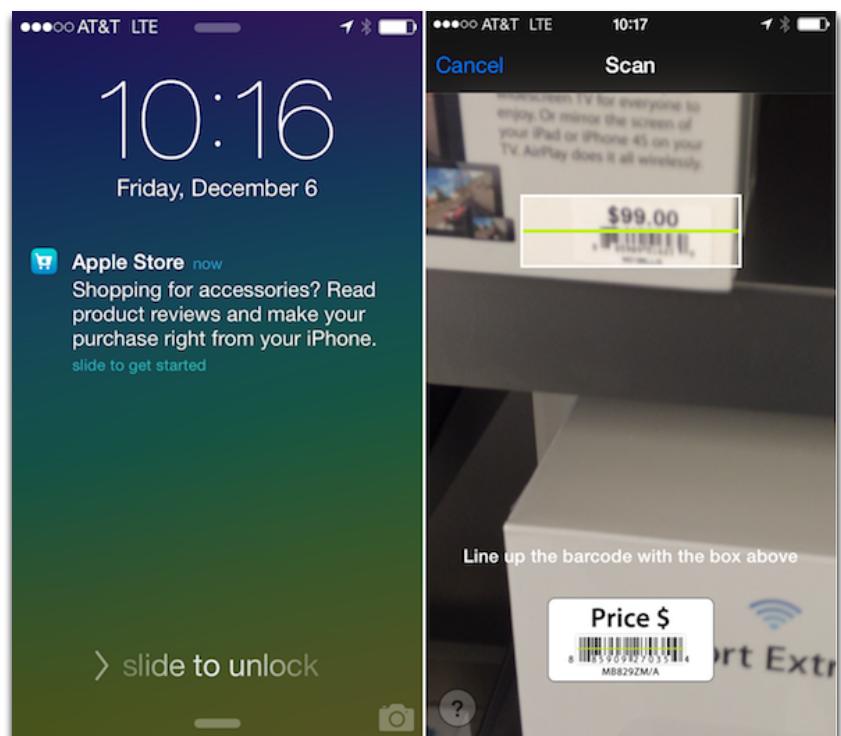
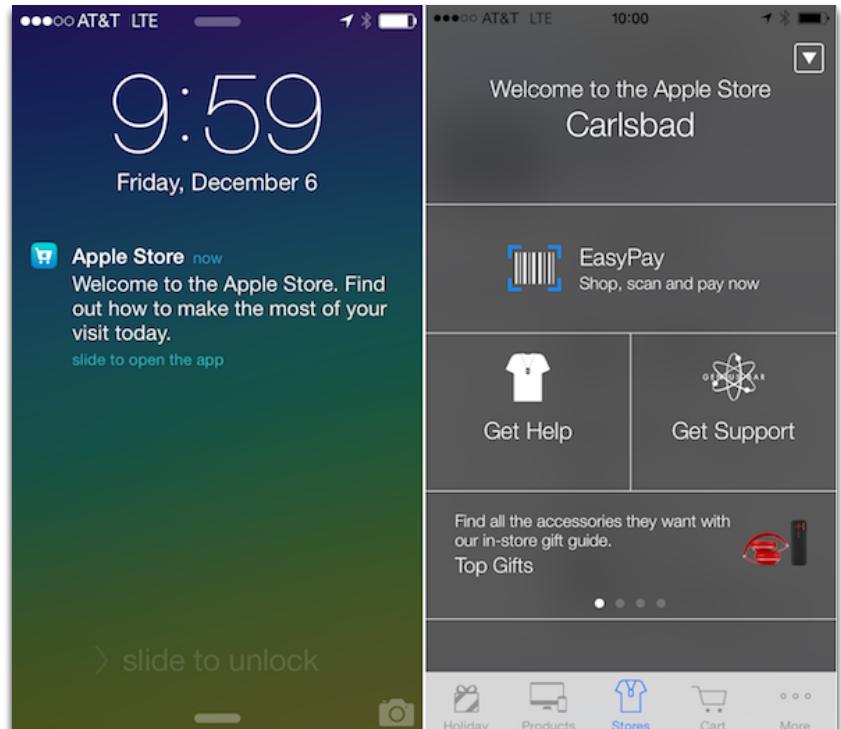
| AR PORTAL





Another Example: iBeacon

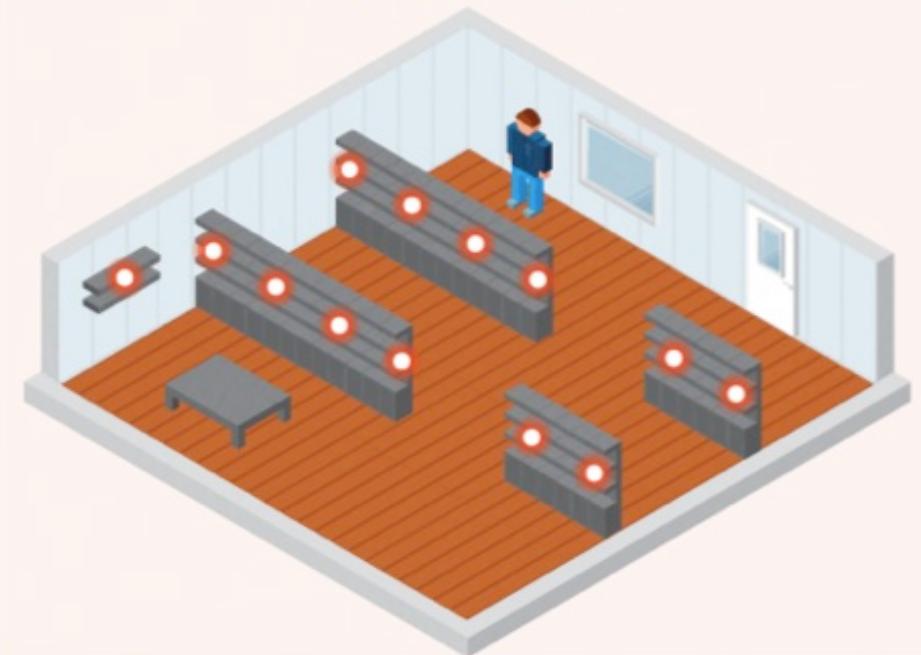
- Announced by Apple in 2013, as a part of iOS7
- Fine-grained location services
- To increase foot traffic to stores
- To reduce showrooming
- Installed in 250+ Apple stores
- To create experiences around physical locations, such as ...



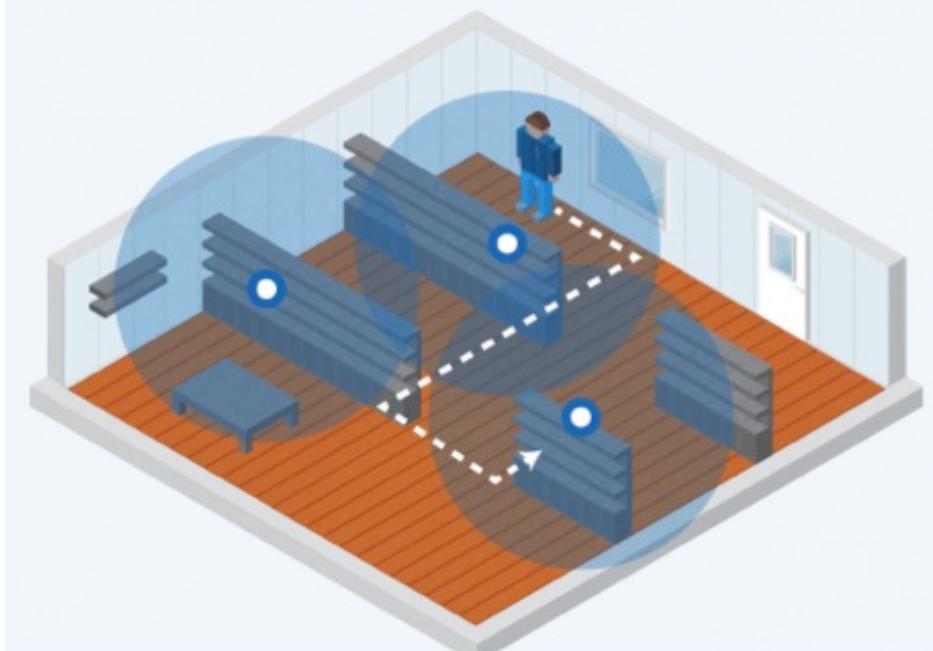
Beacons and NFC

- BLE Beacons continually transmit a discovery signal received by BLE-enabled smartphones
- NFC tags communicate when close to an NFC-enabled smartphone
- BLE beacons' coverage radius can be multiple feet/meters
- NFC tags' coverage radius is centimeters

Wireless transmitter's (NFC Tags) coverage radius is very small.
Measured in centimeters.



Wireless transmitter's (BLE Beacons) coverage radius varies according to signal strength. Measured in Feet.



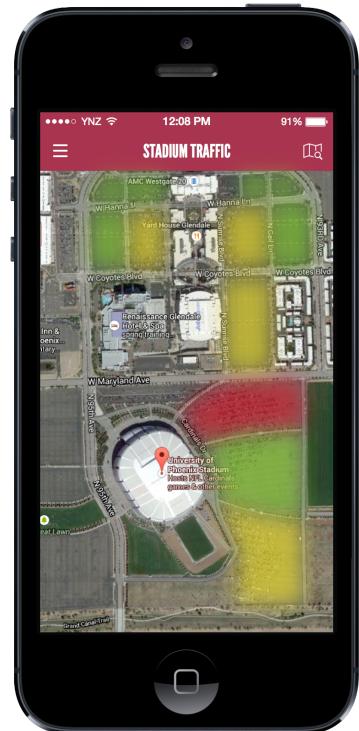
Sports Industry

- Beacons installed in several stadiums and venues
- Works with the venue/team/league app
- Experiences associated with physical artifacts (hall of fame)
- Loyalty programs, season-ticket holder experiences



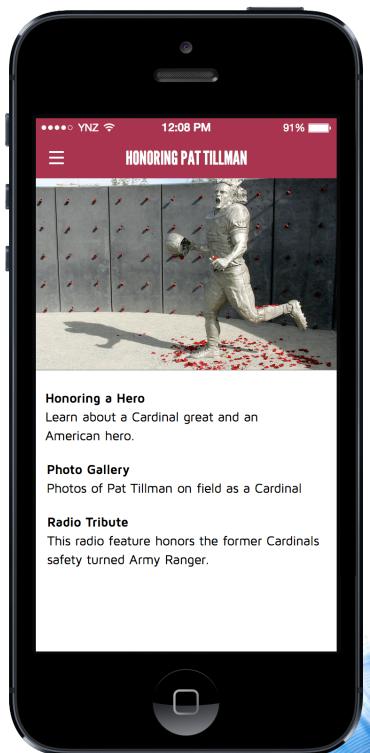


Out-of-stadium
ingress, egress &
parking congestion



In-stadium congestion Wait-times

Interactive exhibits

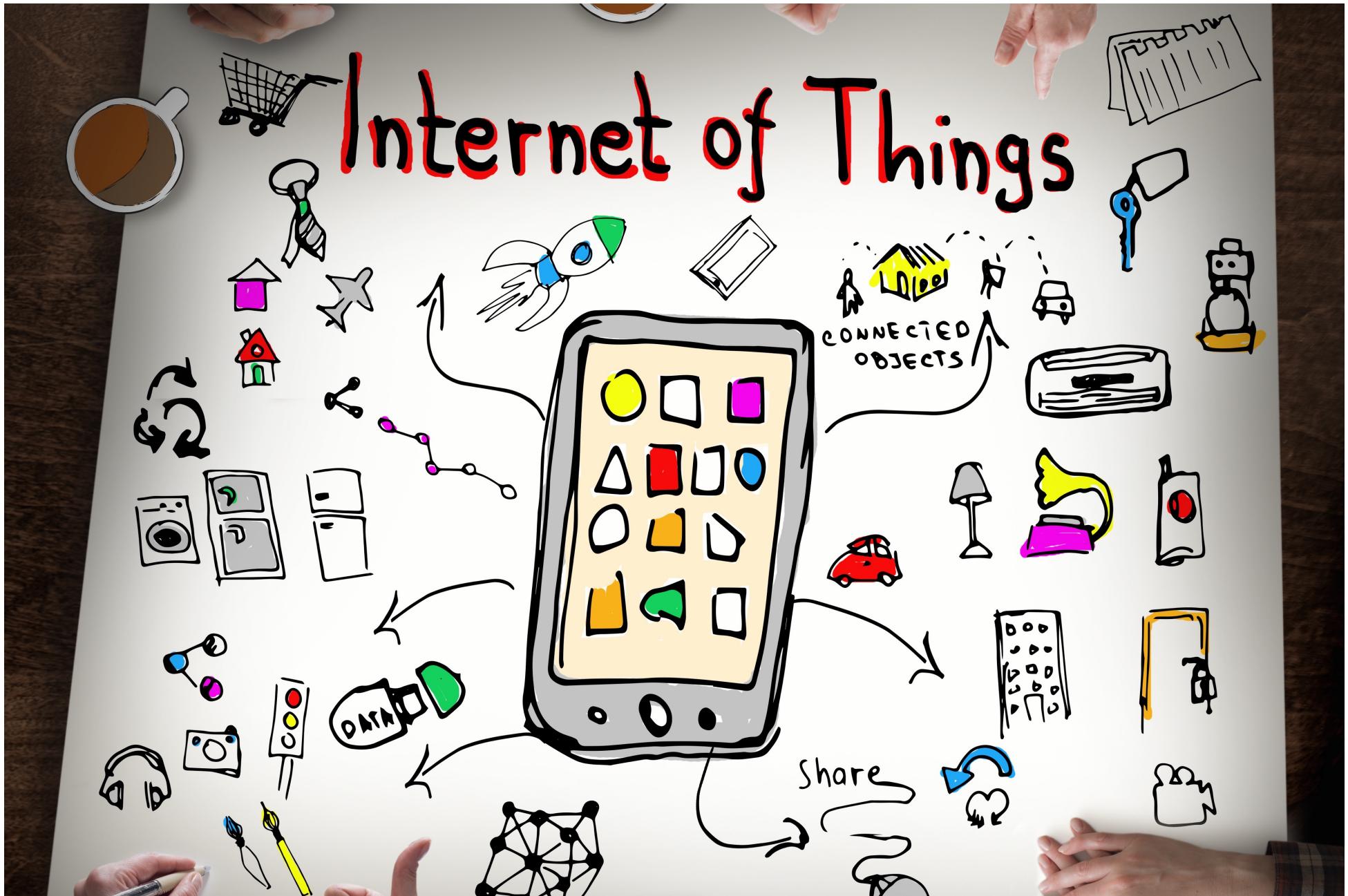


Beacon-Activated Fan Journey



It's amazing what a group of Carnegie Mellon students can do!

Internet of Things



What is the Internet of Things?

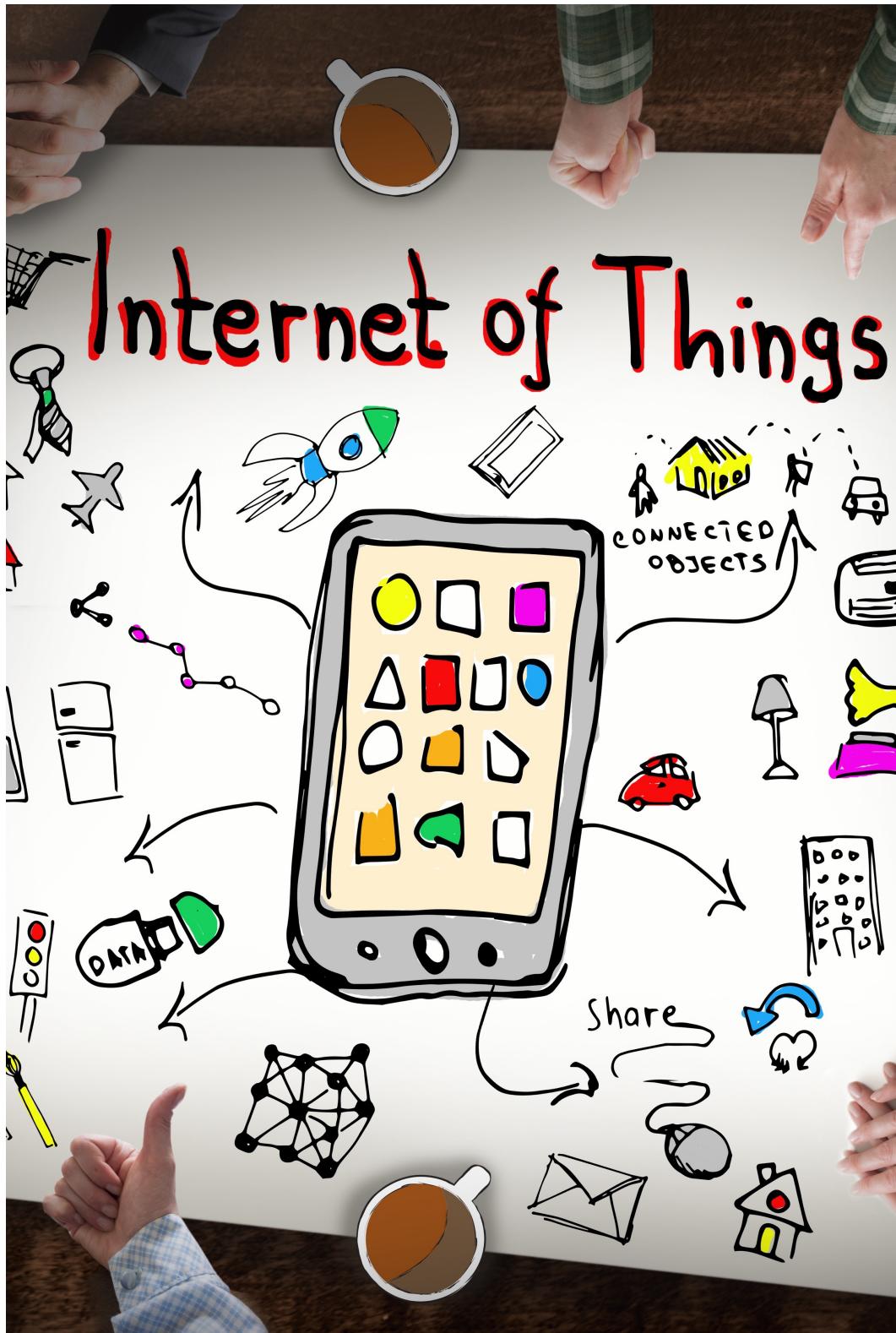
What is IoT?

- ◆ Network of physical objects
 - ◆ Each being uniquely addressable
 - ◆ Each with some kind of “smarts”
 - ◆ Each built to sense/react/interact
 - ◆ Each possibly purpose-built
 - ◆ People can be objects, too
- ◆ What emerges if
 - ◆ You put them together?
 - ◆ They communicate with each other?
 - ◆ New capabilities could emerge?
- ◆ Massive network of
 - ◆ Deeply-embedded devices+people



Trends & Predictions

- ◆ Gartner's 2013 report predicts
 - ◆ 26B IoT "things" by 2020
 - ◆ (Only 7.3B phones/PCs/tablets)
 - ◆ \$300B IoT-traceable added revenue
 - ◆ Every device born with connectivity
- ◆ What the future will bring
 - ◆ New business models
 - ◆ Example: Usage-based insurance
- ◆ Will affect every aspect of our life
 - ◆ Work, home, play, family, travel



Domains (Verticals)

◆ Healthcare

- ◆ In-home patient monitoring
- ◆ In-hospital improved service
- ◆ Tracking of blood, instruments

◆ Retail

- ◆ Improved inventory management
- ◆ In-store customer service
- ◆ Goods across the supply-chain

◆ City/Transportation

- ◆ Improved congestion/traffic flow
- ◆ Improved maintenance of assets
- ◆ Reduced costs, higher efficiency

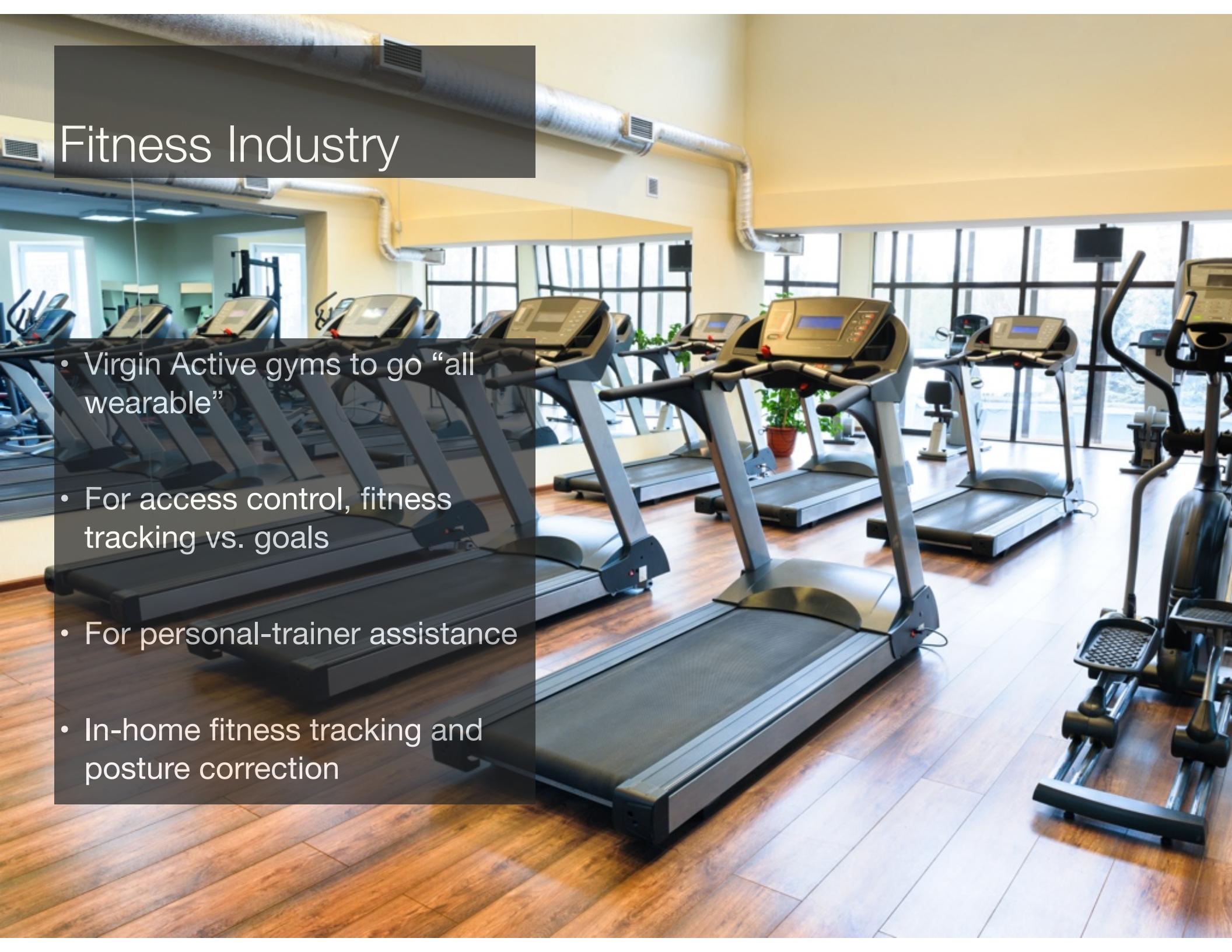


This is already happening



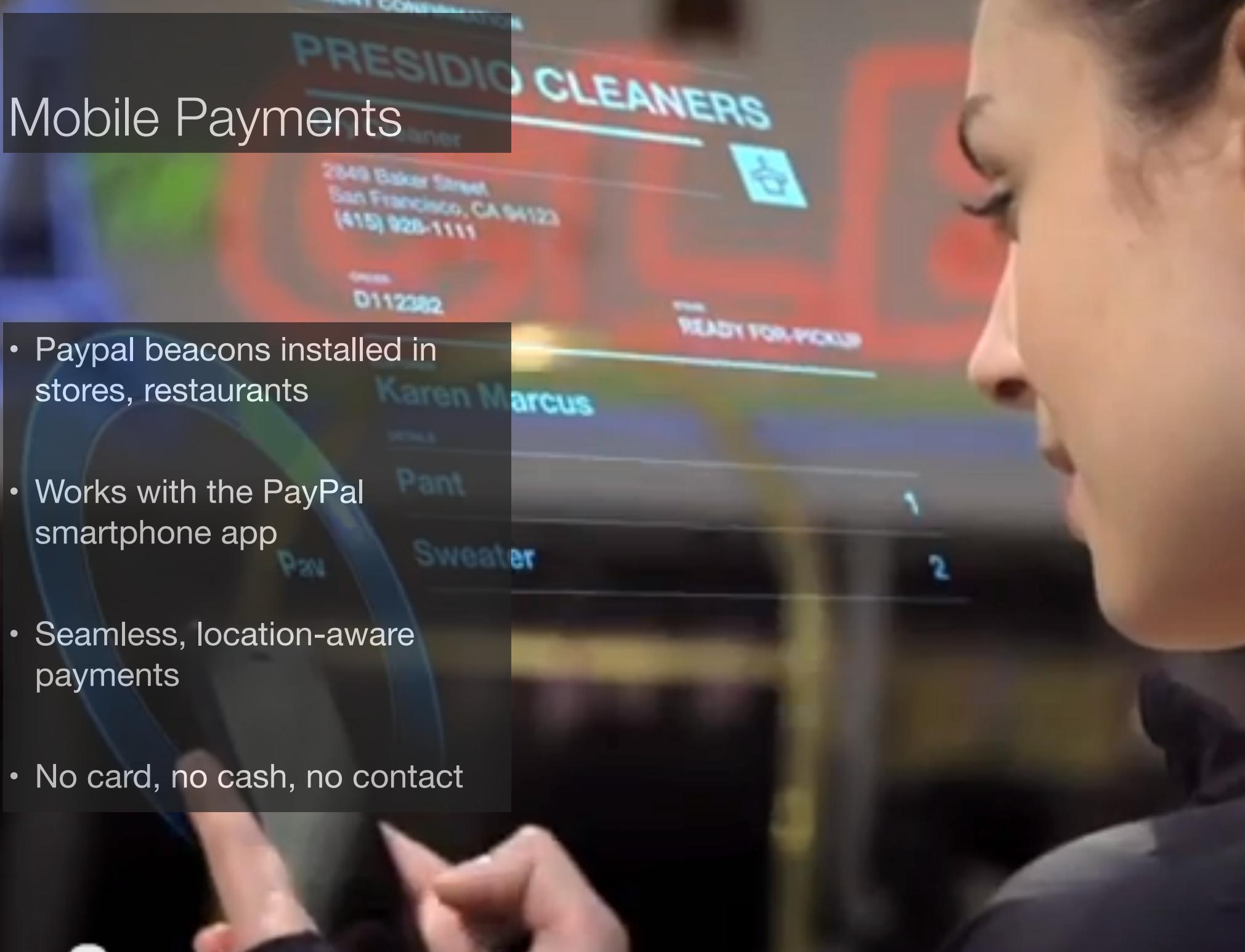
Fitness Industry

- Virgin Active gyms to go “all wearable”
- For access control, fitness tracking vs. goals
- For personal-trainer assistance
- In-home fitness tracking and posture correction



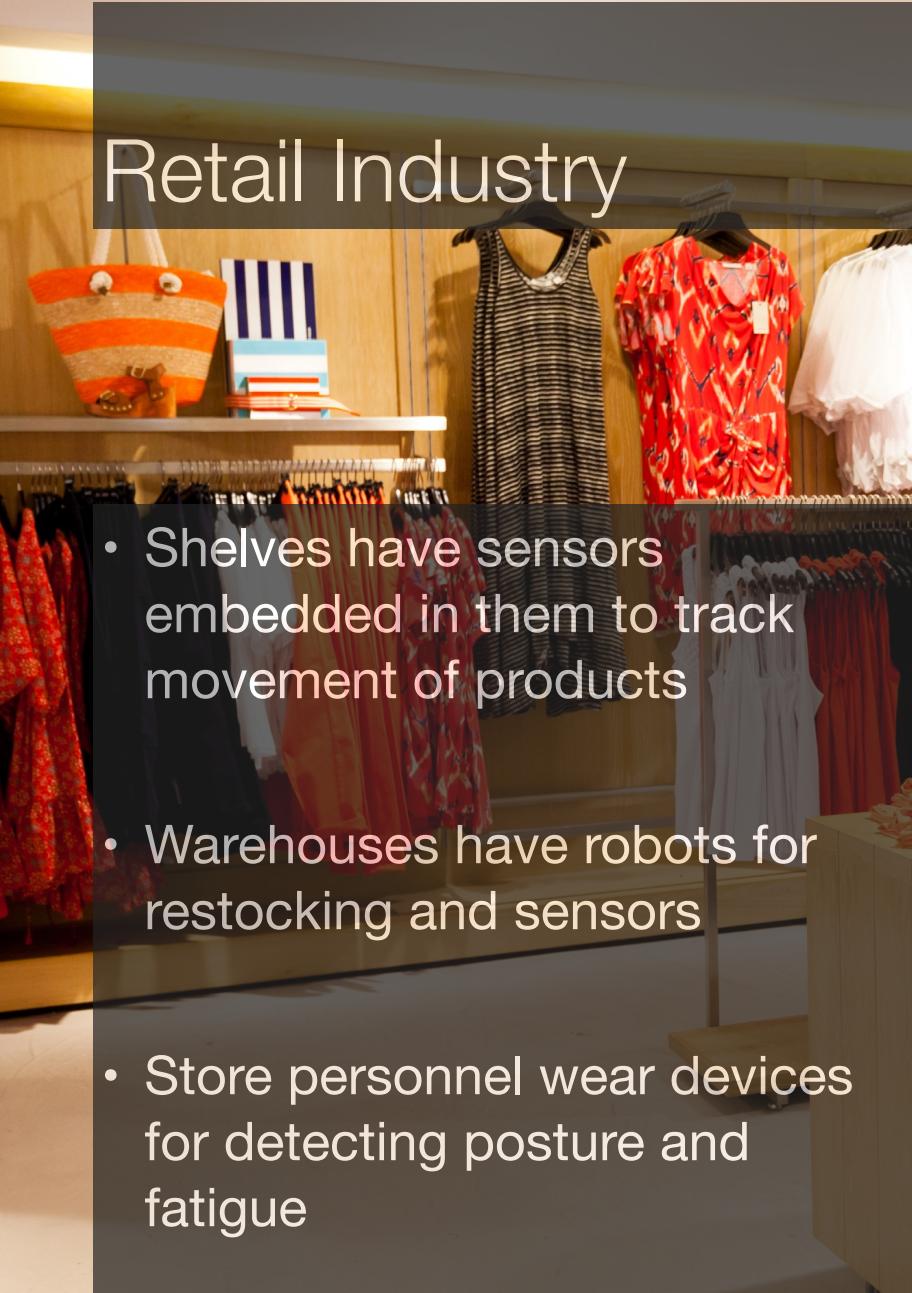
Mobile Payments

- Paypal beacons installed in stores, restaurants
- Works with the PayPal smartphone app
- Seamless, location-aware payments
- No card, no cash, no contact



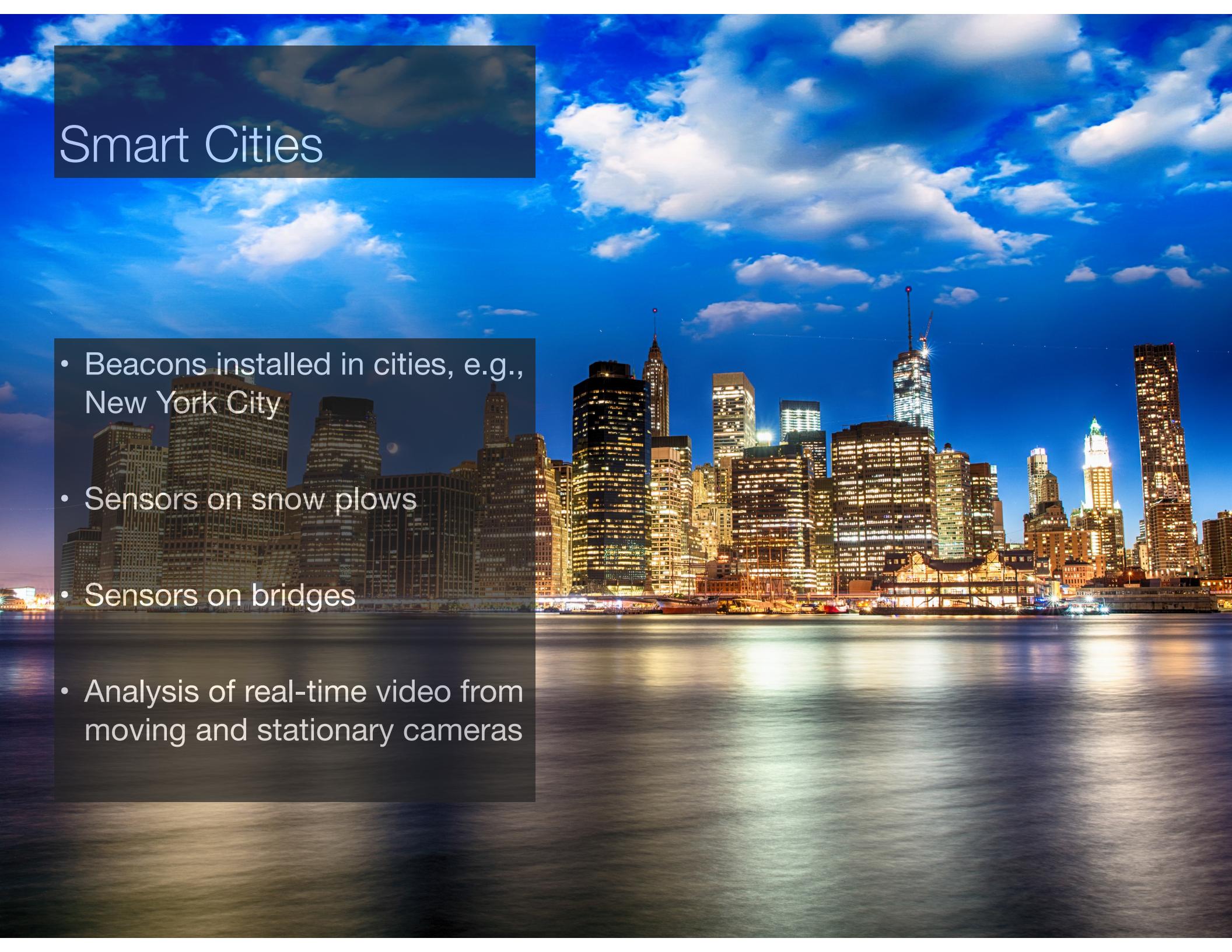
Retail Industry

- Shelves have sensors embedded in them to track movement of products
- Warehouses have robots for restocking and sensors
- Store personnel wear devices for detecting posture and fatigue



Smart Cities

- Beacons installed in cities, e.g., New York City
- Sensors on snow plows
- Sensors on bridges
- Analysis of real-time video from moving and stationary cameras



Libelium Smart World

Air Pollution

Control of CO₂ emissions of factories, pollution emitted by cars and toxic gases generated in farms.

Forest Fire Detection

Monitoring of combustion gases and preemptive fire conditions to define alert zones.

Wine Quality Enhancing

Monitoring soil moisture and trunk diameter in vineyards to control the amount of sugar in grapes and grapevine health.

Offspring Care

Control of growing conditions of the offspring in animal farms to ensure its survival and health.

Sportsmen Care

Critical signs monitoring in high performance centers and fields.

Structural Health

Monitoring of vibrations and material conditions in buildings, bridges and historical monuments.



Quality of Shipment Conditions

Monitoring of vibrations, strokes, container openings or cold chain maintenance for insurance purposes.

Smartphones Detection

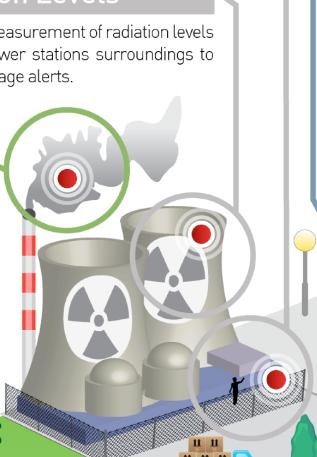
Detect iPhone and Android devices and in general any device which works with WiFi or Bluetooth interfaces.

Perimeter Access Control

Access control to restricted areas and detection of people in non-authorized areas.

Radiation Levels

Distributed measurement of radiation levels in nuclear power stations surroundings to generate leakage alerts.



Electromagnetic Levels

Measurement of the energy radiated by cell stations and WiFi routers.

Traffic Congestion

Monitoring of vehicles and pedestrian affluence to optimize driving and walking routes.



Smart Roads

Warning messages and diversions according to climate conditions and unexpected events like accidents or traffic jams.

Smart Lighting

Intelligent and weather adaptive lighting in street lights.

Intelligent Shopping

Getting advices in the point of sale according to customer habits, preferences or presence of allergic components for the products or expiring dates.

Noise Urban Maps

Sound monitoring in bar areas and centric zones in real time.

Water Leakages

Detection of liquid presence outside tanks and pressure variations along pipes.

Vehicle Auto-diagnosis

Information collection from CanBus send real time alarms to emergency or provide advice to drivers.

Item Location

Search of individual items in big surfaces like warehouses or harbours.

Water Quality

Study of water suitability in rivers and the sea for fauna and eligibility for drinkable use.

Waste Management

Detection of rubbish levels in containers to optimize the trash collection routes.

Smart Parking

Monitoring of parking spaces availability in the city.

Golf Courses

Selective irrigation in dry zones to reduce the water resources required in the green.

Focus of this Course

- ◆ Learn about IoT

- ◆ Platforms (hardware, software)
- ◆ Standards
- ◆ Services (security, dependability)
- ◆ Domains of application

- ◆ Emphasis on IoT-enabled domains

- ◆ Improving refereeing
- ◆ Improving player performance
- ◆ Improving the fan experience
- ◆ Improving the patient experience
- ◆ Improving the stadiums of the future
- ◆ Improving the hospitals of the future
- ◆ Seeing this in action



Entrepreneurship

- ◆ Applying IoT to new products

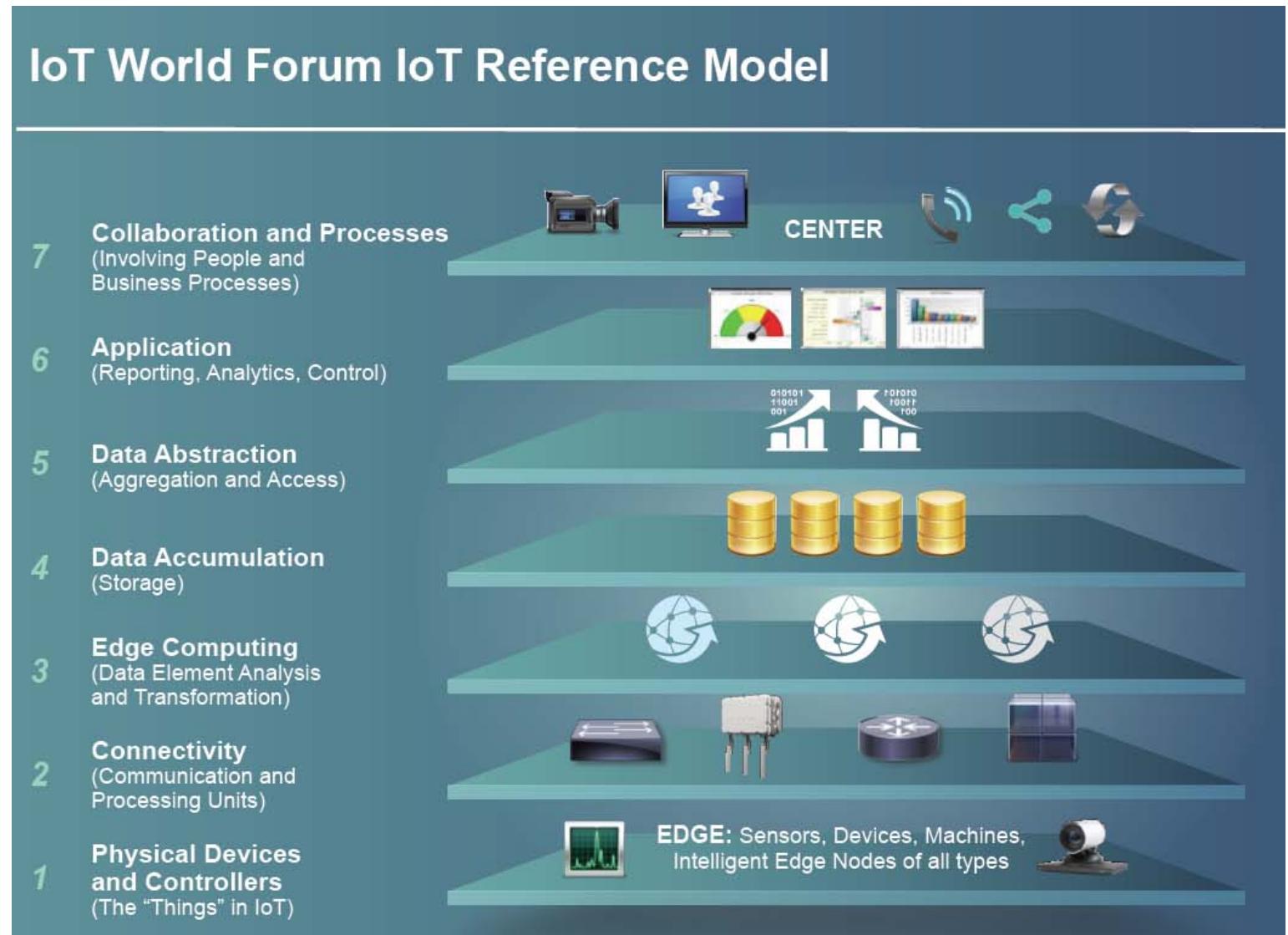
- ◆ Opportunities for products
- ◆ Commercialization practices
- ◆ Product management in industry

- ◆ Emphasis on entrepreneurship

- ◆ Market surveys and studies
- ◆ Understanding ROI
- ◆ Intellectual property
- ◆ How to think about productization



Lecture Coverage



Logistics

- ◆ **Project (Number of team members TBD)**
 - ◆ 30% of your grade
 - ◆ Propose an IoT-enabled sports technology
 - ◆ Must involve hardware
 - ◆ 4-page paper + working prototype + demo
- ◆ **Mid-term exam (Individual)**
 - ◆ 30% of your grade
- ◆ **Final exam (Individual)**
 - ◆ 30% of your grade
- ◆ **In-class talk on IoT sports topic (Individual)**
 - ◆ 10% of your grade





PROJECT EXECUTION

How about the Project?

Project: Presentation (Feb 17-18, in class)

- First in-class team presentation
 - All team members to present jointly
 - Concept, motivation, market, competitive analysis
 - Initial requirements, initial list of parts
- Next few milestones
 - Form teams of four people: 28 January
 - Review your project concepts with me: 4 February
 - Get sign-off on your project idea: 11 February
 - Present your project in class: 17-18 February
 - All parts in hand: 15 February

Project Phases and Expectations

- Concept
- Requirements
- Specification
- Design, architecture, hardware, software, interfaces
- Prototyping – iterative
- Quality assurance (testing, empirical evaluation)
- Packaging and demonstration
- We will cover project expectations every week in class

Project: Grading

- Project counts for 30% of your overall grade
- Grading-related milestones
 - In-class presentation, project proposal — 3% of grade
 - Alpha demo to Priya — 5% of grade
 - Beta demo to Priya — 7% of grade
 - Final demo to Priya — 15% of grade

The Lightning Talk

Individual Lightning Talk counts for 10% of your overall grade

What you need to do for the 10% of your grade

- Do a 15-20 minute talk
- Work with me to refine the talk to present in class
- Pick a topic you are passionate about
- The topic should be in IoT and sports

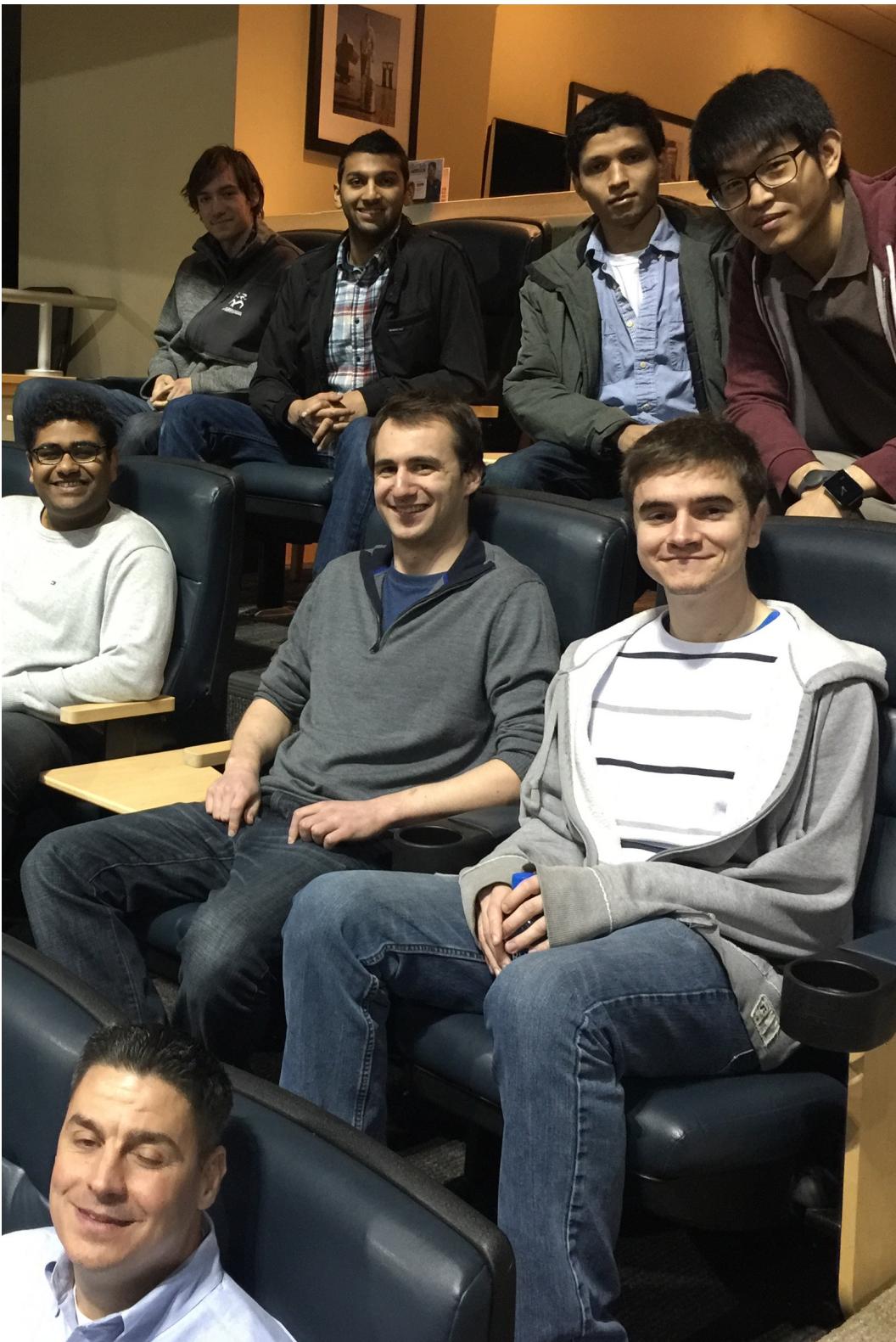
Past Projects

- ◆ Previous projects

- ◆ Visual pacing system
- ◆ Wait-times in stadiums
- ◆ Smart soccer cleats
- ◆ Virtual-reality basketball trainer
- ◆ Smart beverage cup
- ◆ Chucking detection in cricket
- ◆ Anti-theft for bicycles

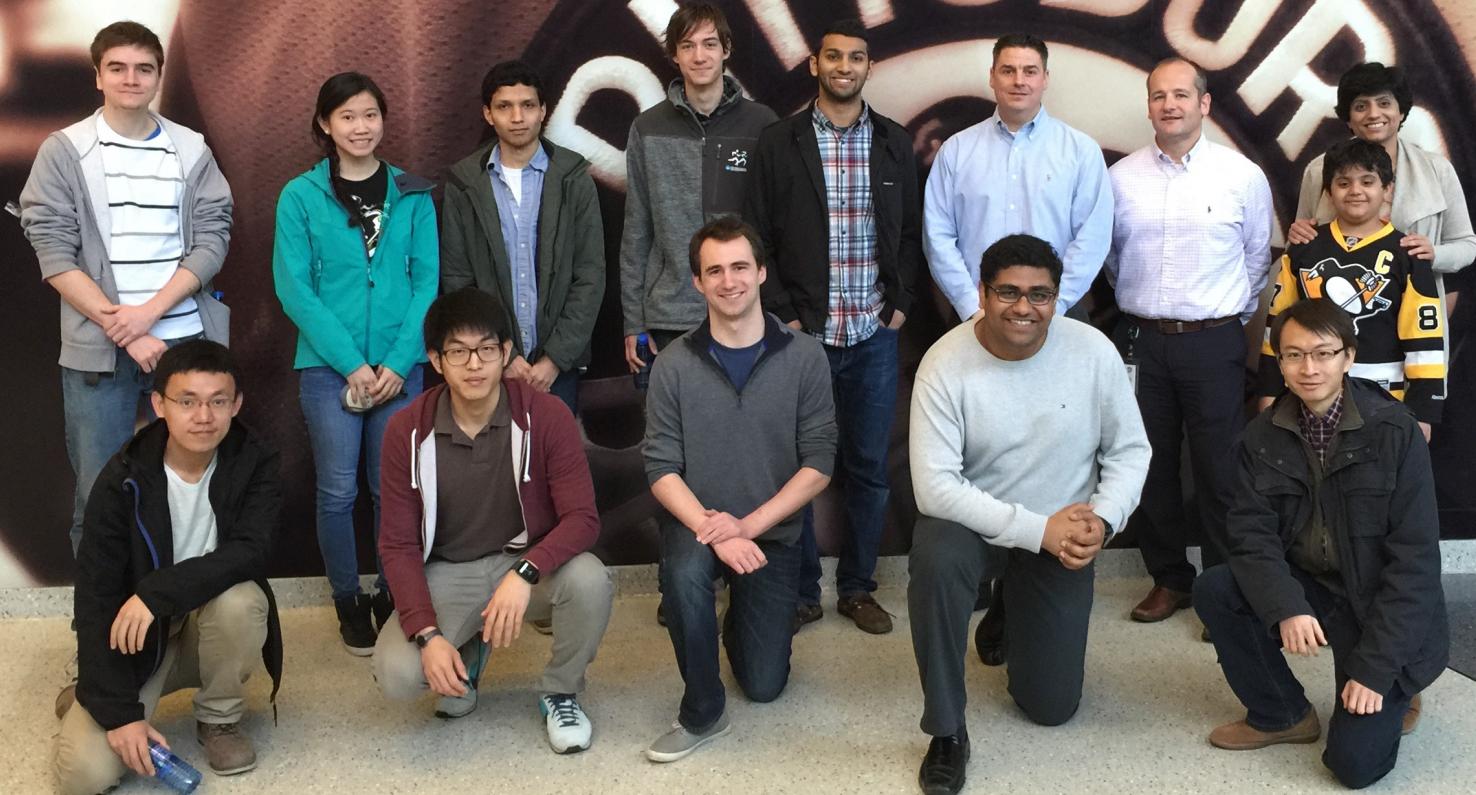
- ◆ Feel free to propose ideas

- ◆ You can pick a domain
- ◆ You can pick the problem
- ◆ We will shepherd you to success



What you should do **NOW**

- Form a group, and start brainstorming
 - What problem are you solving?
 - What is the solution/product that you are proposing?
 - What sport does it work for?
 - Who is the user? Athlete? Coach? Parent? Referee?
 - Who is your competition?
 - In what way is your solution/product/approach novel, or different?
 - What types of components/parts do you need?
 - What do you expect to be able to demo in 10 weeks?



Introduction

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