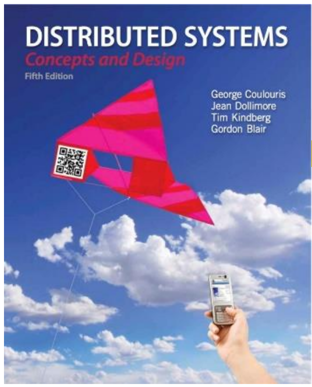

Mobile and Ubiquitous Computing

Concepts are
drawn from Chapter 19

Slides are revised from Dr. Michael R. Lyu at CUHK

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万物并育而不相害，道并行而不相悖，小德川流，大德敦化，此天地之所以为大也。

—— 《中庸》

Review

- Q1: What are the key components of Web Services Infrastructure?

Review

- Q2: What is Simple Object Access Protocol (SOAP)?

Review

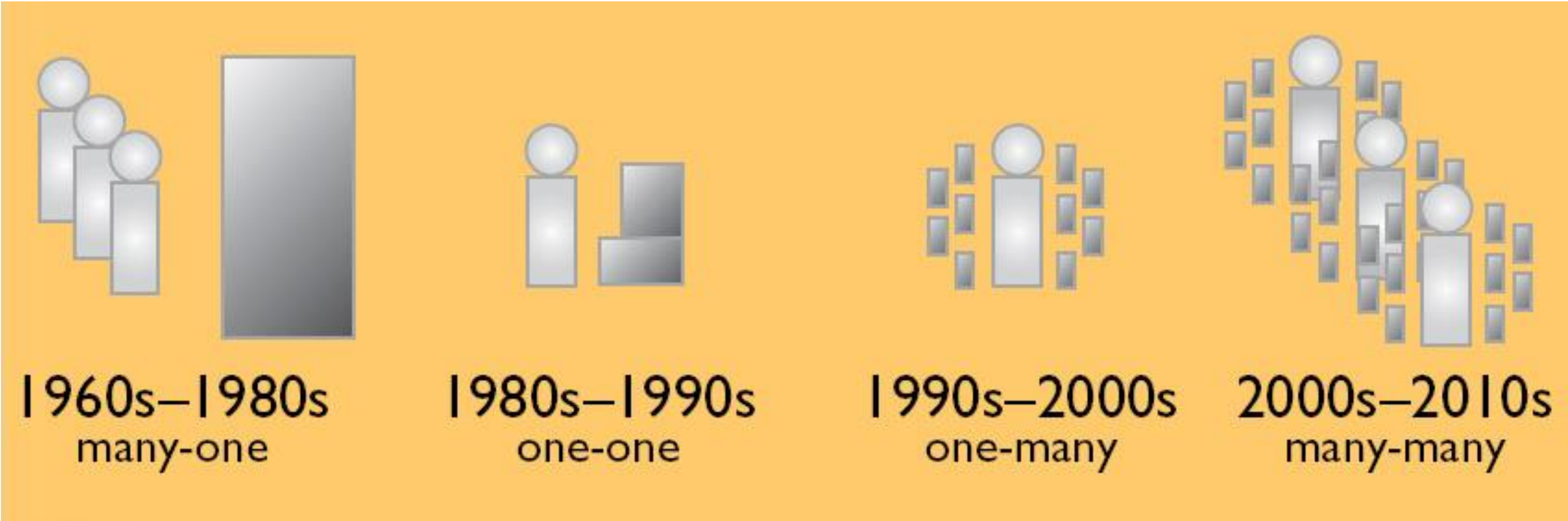
Outline

1. Overview
2. Association
3. Interoperation
4. Sensing and Context-Awareness
5. Summary

Background

- Mobile computing
  - People traveling with their computers while retaining connected to other machines or the Internet
  - Exploit the **connectedness** of devices that **move** around in the everyday physical world
- Ubiquitous Computing
  - Also known as “Pervasive Computing”
  - Means “**to be found everywhere**”
  - Exploiting the increasing **integration** of computing devices with our everyday **physical world**

Background: Computing Evolution



Ubiquitous Computing Era

1 Overview

- The ubiquitous computing vision (Mark Weiser, 1993)
  - “Ubiquitous computing enhances computer use by making many computers available throughout the physical environment, but making them effectively invisible to the user.”
- The purpose of a computer is to help you do something else
- The best computer is a quiet, **invisible** servant
  - Physically invisible – hidden
  - Mentally invisible – not centers of attention
    - *The more you can do by* ***intuition*** *the smarter you are*
    - *The computer should extend your* ***unconscious***
- Technology should create calm

1 Overview

- IBM’s definition of Pervasive Computing
  - “Convenient access, through a new class of appliances, to relevant information with the ability to easily take action on it when and where you need to.”
- Numerous, casually accessible, often invisible computing devices
- Frequently mobile or embedded in the environment
- The aim is for easier computing, more available everywhere when it's needed




1.1 Introduction: Characteristics

- Ubiquitous/Pervasive computing characteristics

Physical Integration

- integration between computing nodes and the physical world

1.1 Introduction: Time Are Changing

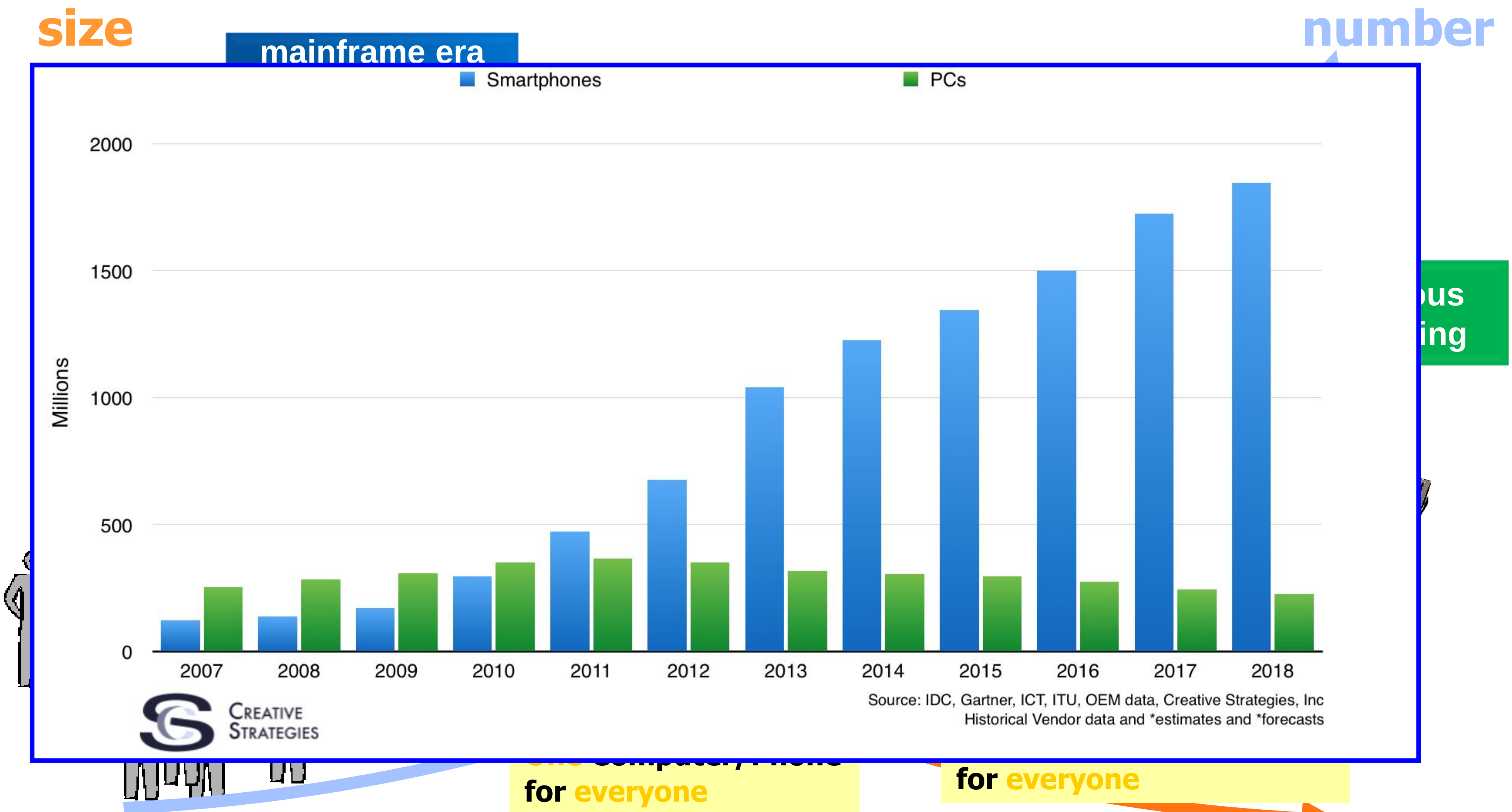
In 19th century, energy triggered the industrial revolution → **Decentralizing energy**

In 20th century, computing power triggered another economic revolution → **Decentralizing computer power**

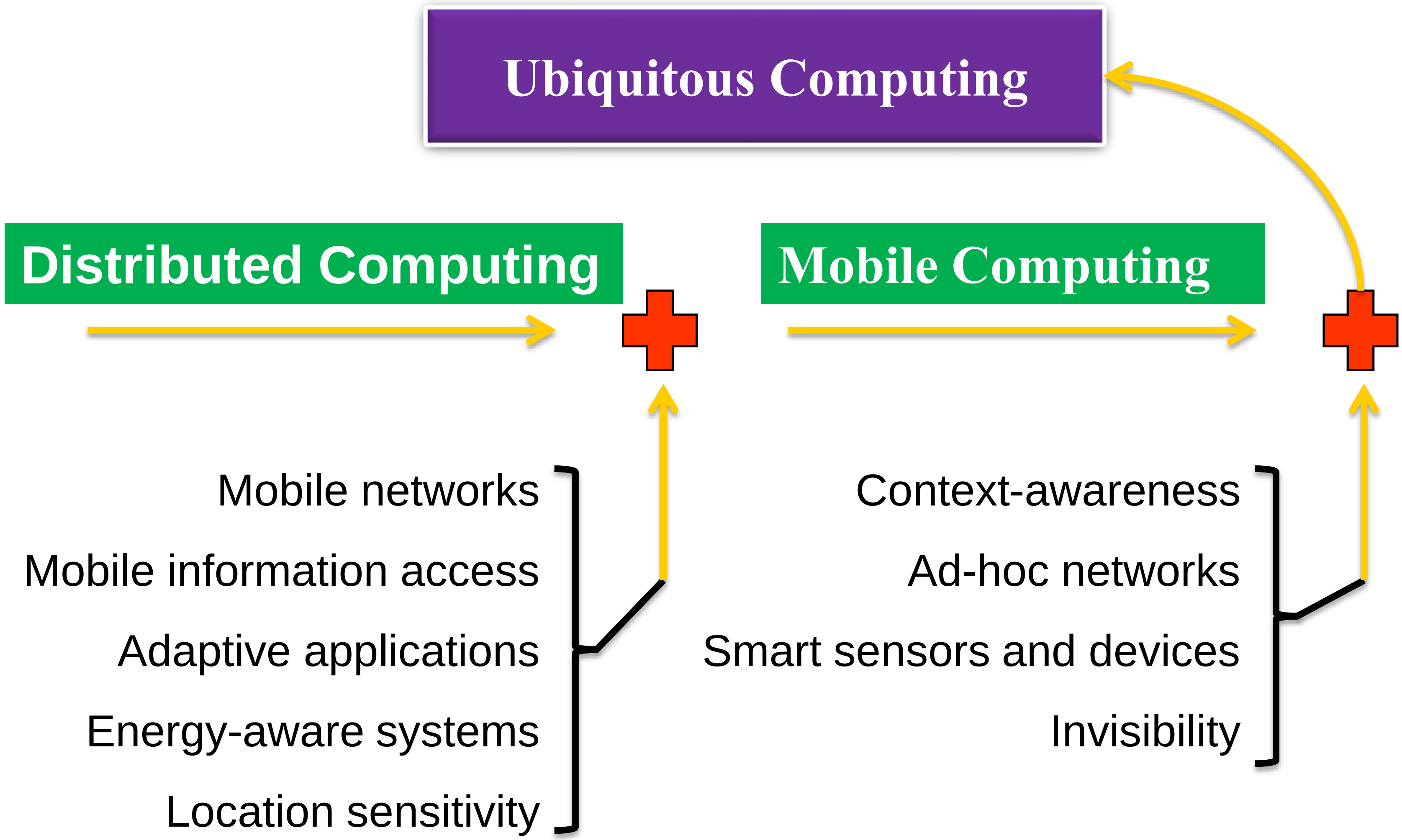
Entering 21st century, Internet is a worldwide network for everyone → **Decentralizing connectivity**

Everywhere at anytime: Ubiquitous Computing

1.1 Introduction: Major Trends in Computing



1.1 Introduction: The Relationships



1.1 Introduction: Where Do We Currently Stand?

- Ubiquitous devices (always “at hand”)
  - Tab: accompanied or wearable centimeter sized devices
    - *e.g., smartphones, smart cards*
  - Pad: hand-held decimeter-sized devices
    - *e.g., laptops*
  - Board: meter sized interactive display devices
    - *e.g., horizontal surface computers and vertical smart boards*





1.1 Introduction: Where Do We Currently Stand?

- Ubiquitous networks (always available)
  - (W)LAN/MAN
    - *Ethernet, IEEE 802.11*
  - PAN (Personal Area Network)
    - *Bluetooth, BLE, IrDA, NFC, etc.*
  - GSM/GPRS/3G/4G/5G
- Ubiquitous services
  - Currently mostly “location-based”

1.1 Research in Ubiquitous Computing Area

- Top Conference in area: UbiComp

2021UBiCOMP

Home Attending Program For Authors Accessibility Calls Organizers

September 21 — 26
All Over the World

Registration Now Open!

Areas Of Interest Include (But Are Not Limited To):

- WEARABLE SYSTEMS, NOVEL DEVICES AND FORM FACTORS
  - Smartphone- and smartwatch-based systems and applications
  - Glasses
  - Earables
  - Rings and Gloves
  - Textiles and clothing
  - On-skin interfaces
  - Insertables and implantables
  - Animal computer interaction
  - Personal protective equipment, including face masks, face shields.
- ENABLING TECHNOLOGIES
  - Displays, mobile augmented reality optics (freeform optics, lightguides, holographic and diffractive approaches)
  - Haptics and actuators
  - Novel sensor technologies enabling and enhancing context-aware sensing, including but not limited to:
    - Sensing the body (movement, behaviour, physiology)
    - Sensing the eye (gaze, patterns of looking, eye-computer interaction)
    - Sensing the brain (wearable fNIRS, EEG, brain-computer interfaces)
  - Wearable sensor networks
  - Manufacturing of wearable technologies
  - Wearable technology toolkits
  - Power sources and management, thermal management

- TEXTILES AND CLOTHING
  - E-textiles, advanced textiles, and clothing-based wearables
  - Functional clothing and non-electronic wearable technologies
  - Novel materials for textiles and clothing
  - Exoskeletons and physical strength augmentation
- ON-SKIN AND IMPLANTABLE INTERFACES
  - On-skin technology and interfaces
  - Implantable, insertable technology and interfaces
  - Unconventional materials and form factors for close-body devices
  - Biotechnology and HCI
  - Microfluidics for on-skin interfaces
- DESIGN PROCESS FOR WEARABLES
  - Research through design
  - Craft and computing for wearables
  - Culturally-sensitive design processes
  - Design and conceptual innovation in wearables
  - From basic research to commercial product

1.2 Volatile System

- A common model for mobile and ubiquitous computing
- Certain **changes** are common rather than exceptional
- Relevant forms of volatility include
  - Failures of devices and communication links
  - Changes in the characteristics of communication
    - *such as bandwidth*
  - The creation and destruction of **association** between software components resident on the devices
    - *association: logical communication relationships*

1.2.1 Volatility: Smart Spaces

- Physical spaces
  - Form background for mobile/ubiquitous computing
- **Smart spaces**: environments within which volatile systems are presented
  - Physical space where embedded services
    - *Wild, open space without infrastructure*

      Such as environmental monitoring
    - *Or relatively stable computing infrastructure*

      Such as room, building, town square, or train carriage

1.2.1 Smart Spaces

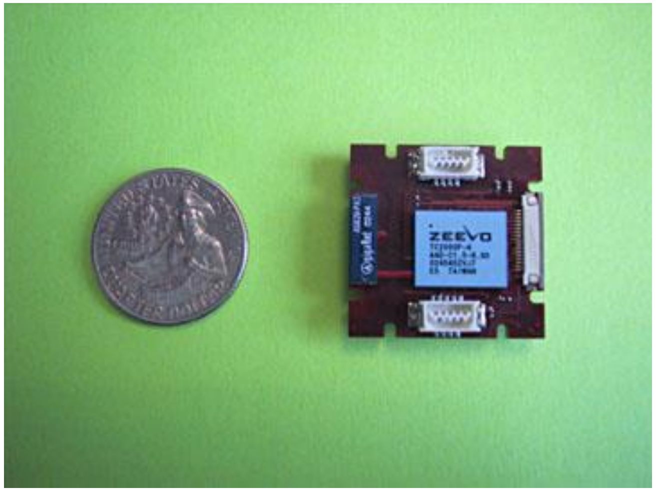
- Movement into and out of smart spaces
  - Physical mobility
    - *Smart spaces act as environments for devices to visit and leave*
  - Logical mobility
    - *process or agent may move in or out of a smart space or a personal device*

1.2.2 Volatility: Device Model

- New class of computing device
  - Limited energy
    - *Smaller and lighter device has lower battery capability*
  - Resource constraints
    - *Limited processor speed, storage capability and network bandwidth*
  - Sensors and actuators
    - *Sensors: devices that measure physical parameters*
    - *Actuators: software-controllable devices that affect the physical world*

1.2.2 Device Examples

- Motes
  - Devices intended for autonomous operations such as environment sensing.



1.2.2 Device Examples

- Smart phone
  - A mobile phone built on a mobile computing platform, with more advanced computing ability and connectivity than a feature phone

1.2.3 Volatility: Volatile Connectivity

- Wireless connection technologies
  - e.g. Bluetooth, WiFi, 3G, 4G, 5G, etc.
  - Vary in their nominal bandwidth and latency, and communication costs
- Volatility of connectivity
  - Variability at runtime of the state of connection or disconnection between devices
  - The QoS between devices

1.2.4 Volatility: Spontaneous Interoperation

- Association
  - **Logical relationship** formed when at least one of a given pair of components communicates with the other over some well-defined period of time
  - Association is distinct from (physical) connectivity
- Interoperation
  - The **interactions** during the association

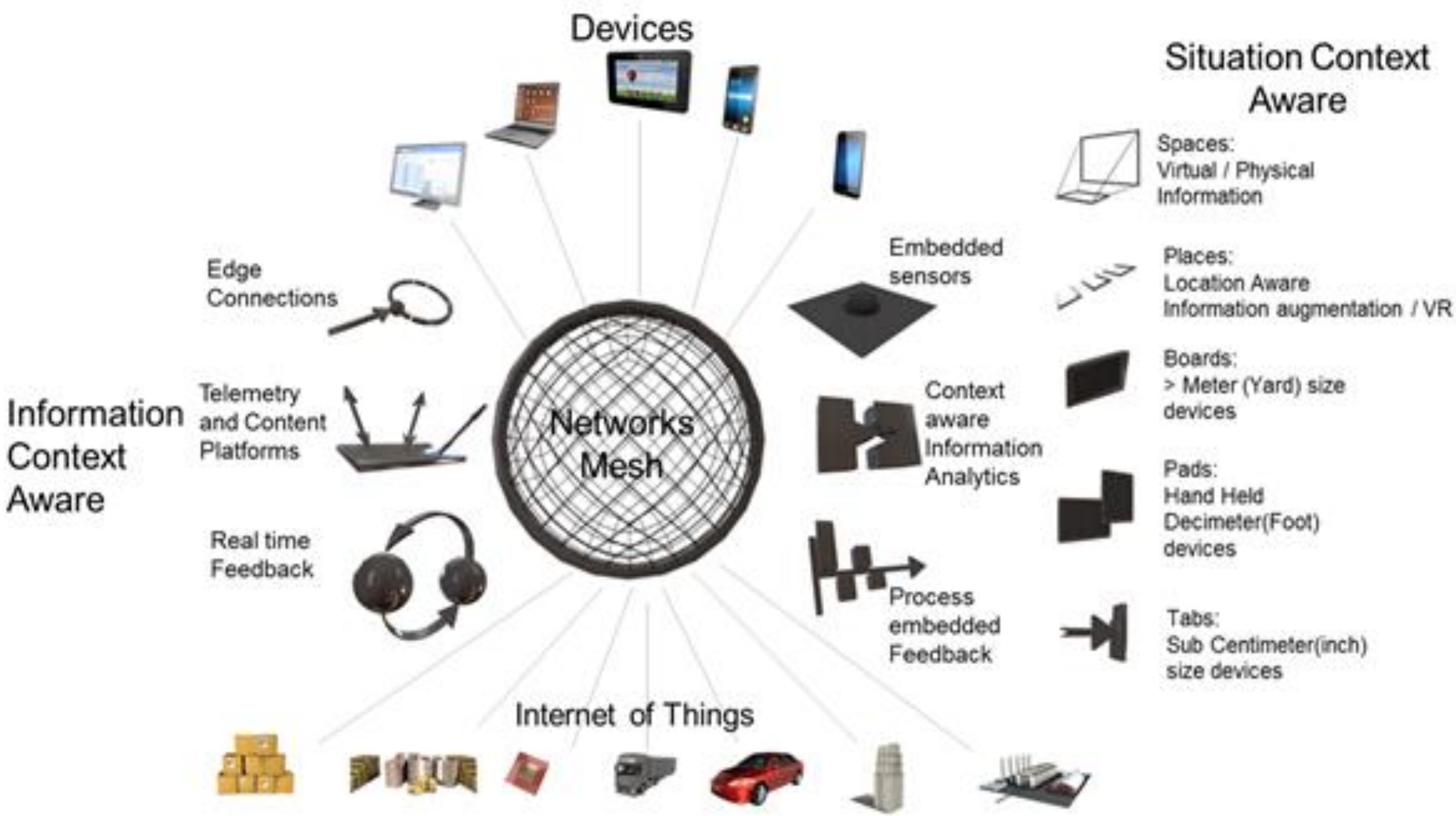
1.2.4 Examples of Pre-configured versus Spontaneous Association

Pre-configured	**Spontaneous**
Service-driven: *email client and server*	

1.3 New Services with Ubiquitous Computing

- Services are an important counterpart to technology
- New services increase the value for the user
- Examples:
  - Ubiquitous Systems
  - Ubiquitous Healthcare
  - Smart Homes
  - Ubiquitous City

1.3.1 Ubiquitous Systems



1.3.2 Ubiquitous Healthcare

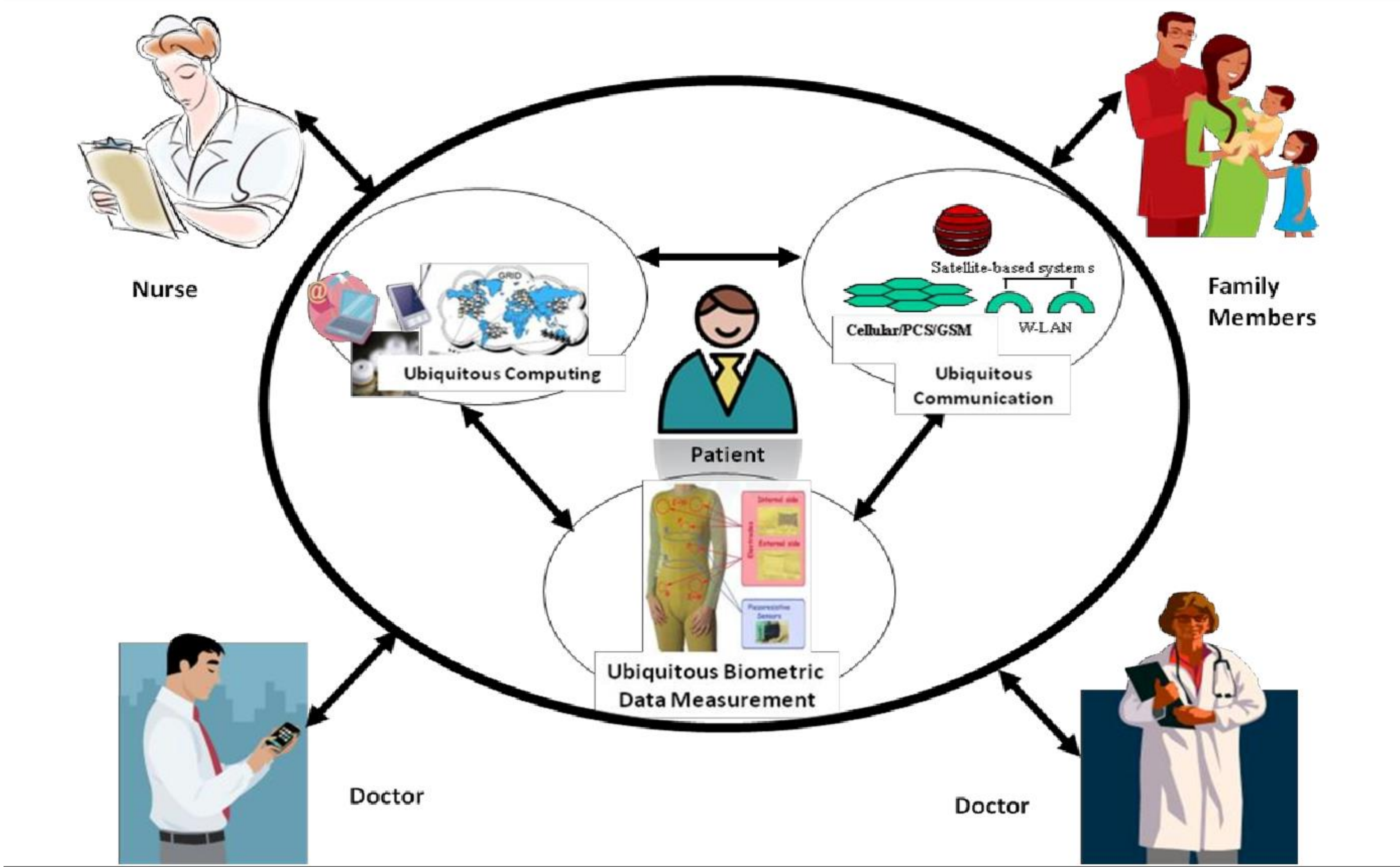
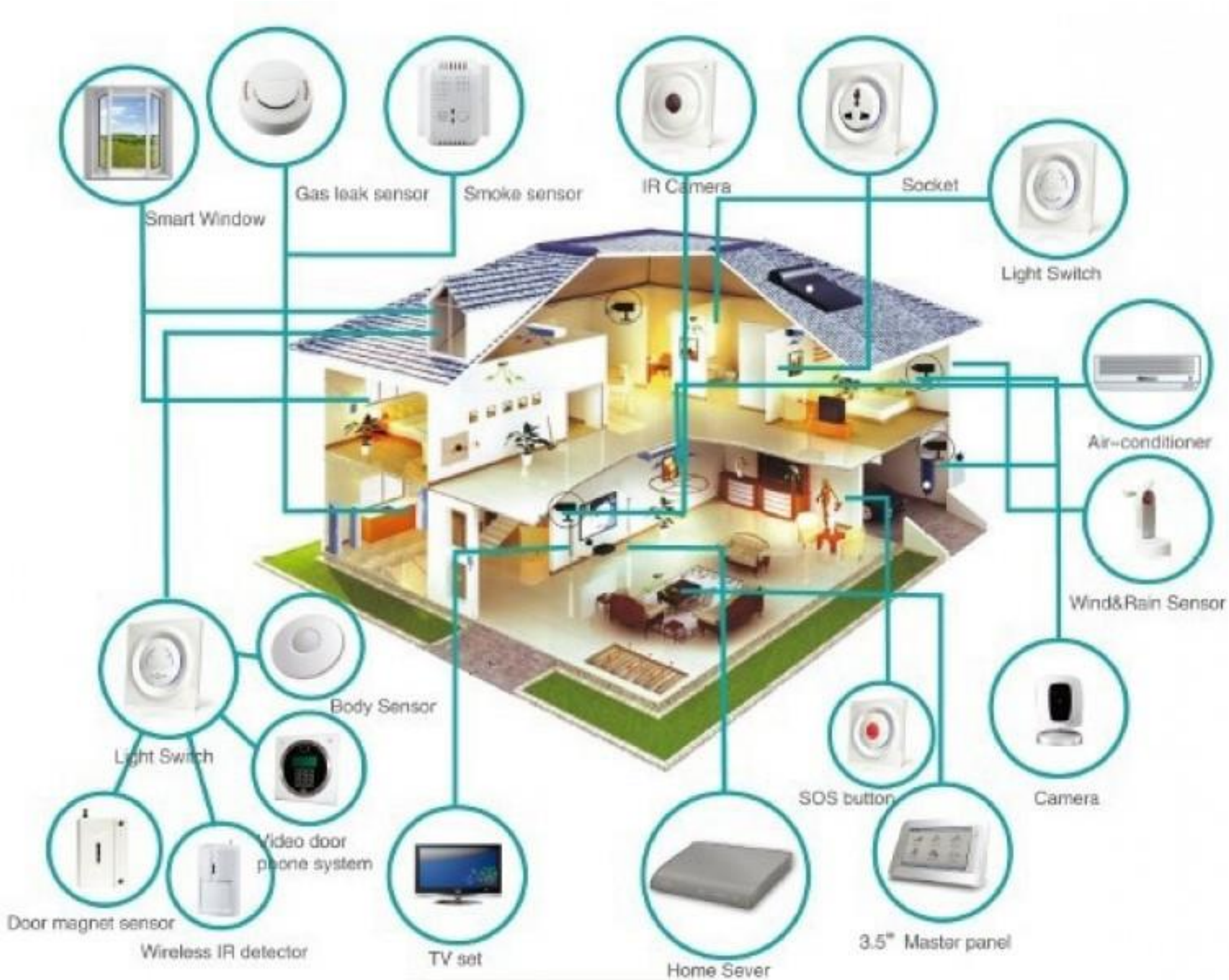


Figure 1. Conceptual Model of Ubiquitous Healthcare Environment

1.3.3 Smart Homes



1.3.4 Ubiquitous City

2 Association

- Volatile components need to interoperate
  - A device appearing in a smart space need to bootstrap itself in the network to enable communication
  - Preferably without user intervention
- Network bootstrapping
  - Communication takes place over a local network
  - The device must first acquire an address on the local network or register a name
- Association
  - Components on the device either associate to services in the smart space or provide services to components elsewhere in the smart space, or both

2 Association

- Association problem
  - How to associate appropriately within a smart space?
- Solutions should address two main aspects
  - Scale: efficiently choosing interoperating components
  - Scope: constrain the association within the smart space
- Boundary principle
  - Smart spaces need to have system boundaries that correspond accurately to meaningful spaces as they are normally defined territorially and administratively

2.1 Discovery Services

- One attempt at solving the association problem
- A discovery service is a directory service in which services in a smart space are **registered** and **looked up** by their attributes
- Takes account of volatile system properties
  - The directory data is dynamically determined as a function of the client's context
  - No infrastructure to host a directory server
  - Services in the directory may spontaneously disappear
  - Need to be sensitive to the energy and bandwidth

2.1 Major Components in Service Discovery Protocols

1 Service and attribute naming

- Template-based
- Template-based and predefined

- A client searches a service by specifying a service name and attributes
- Many discovery protocols use a template-based approach to naming
- Several protocols offer a predefined set of common attributes and frequently used service names

2.1 Major Components in Service Discovery Protocols

2 Initial communication method

- Unicast
- Multicast
- Broadcast

- Unicast is the most efficient initial communication method
  - Requiring to configure network addresses with prior knowledge
- User Datagram Protocol multicast
  - Only need to set a few multicast addresses initially
- Broadcast
  - Usually limited within a single hop of wired or wireless networks

3 Discovery and registration

- Query-based
- Announcement-based

- Clients, services, and directories have two basic options for exchanging discovery and registration information
- Query-based
  - A party receives an immediate response to a query and doesn't need to process unrelated announcements
- Announcement-based
  - Interested parties listen on a channel. When a service announces its availability and information, all parties hear the information.

4 **Service discovery infrastructure**

- Directory-based
- Nondirectory-based

- The directory-based model has a dedicated component: a directory
  - Flat directory structure
  - Tree-like hierarchical directory structure
- The nondirectory-based model has no dedicated component.
  - When a query arrives, every service processes it
  - If the service matches the query, it replies

2.1 Major Components in Service Discovery Protocols

5 Discovery scope

- Network topology
- User role
- Context

- Network topology
  - Some protocols use LANs as the default, while others use a single-hop wireless network range
- User role
  - Support administrative domains as a discovery scope
  - Reflect an ambient environment according to a user's roles
- Context
  - High-level context information such as temporal, spatial, and user activity information

2.1 Major Components in Service Discovery Protocols

6 **Service usage**

- Explicitly released
- Lease-based

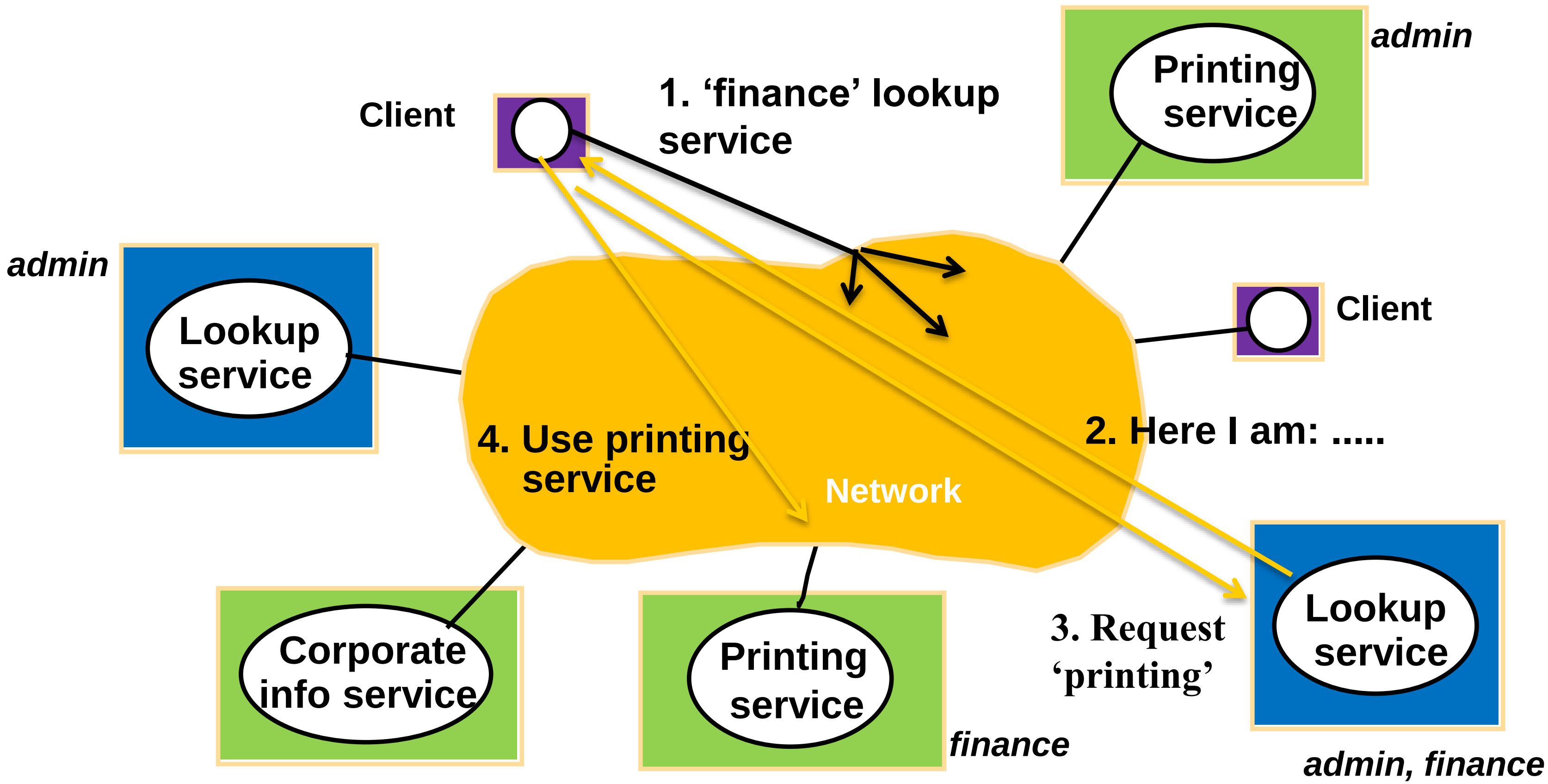
- In some service discovery protocols, a client must explicitly release a service's resources once service usage is granted
- Lease-based mechanism
  - A client and a service negotiate a service usage period, which the client can later cancel or renew

2.1 Sample Interface to a Discovery Service

Methods for service de/registration	Explanation
lease := register(address, attributes)	Register the service at the given address with the given attributes; a lease is returned
refresh(lease)	Refresh the lease returned at registration
deregister(lease)	Remove the service record registered under the given lease
Method invoked to look up a service	
serviceSet := query(attributeSpecification)	Return a set of registered services whose attributes match the given specification

2.1 Service Discovery in Practice

1. Jini's discovery protocol



2.1 Service Discovery in Practice

2. Bluetooth
   - Bluetooth is a short-range RF-based (non-IP-based) communication technology
   - Discoverability is based on actual physical proximity, rather than closeness in the IP routing infrastructure
   - Separates device discovery from the discovery of services on a given device
     - *Higher level: Bluetooth Service Discovery Protocol*
     - *Lower level: Link Manager Protocol and Logical Link Control and Adaptation Protocol*

2.2 Physical Association

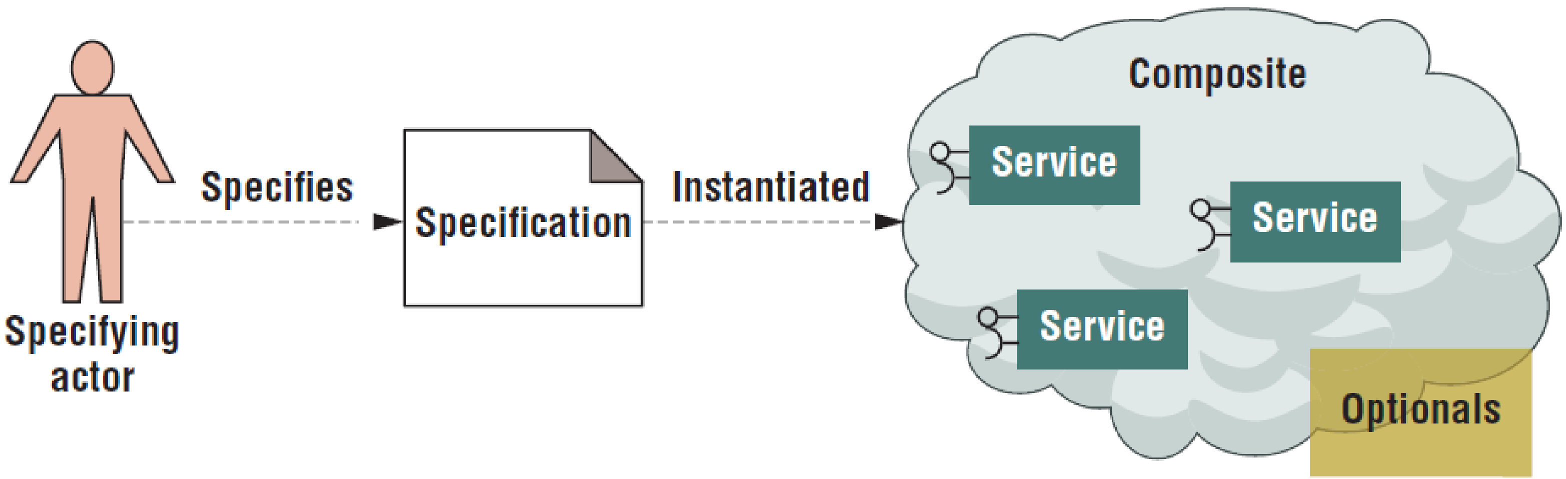
- Shortcomings of network discovery service systems
  - The use of subnet (a poor approximation to a smart space)
  - Inadequacies in the way services are described
- The shortcomings of network discovery systems can be solved to some extent using physical means
  - Solutions often require human involvement (the next slide)

2.2 Techniques on Physical Association

- Human input to scope discovery
- Sensing and physically constrained channels to scope discovery (e.g., GPS)
- Direct association
  - Address-sensing
  - Physical stimulus
  - Temporal or physical correlation

2.3 Service Composition

- Combining existing services to create new pervasive computing services
- A frequently emphasized feature of ubiquitous computing is the **ad hoc**, seamless composition of services from **various** devices



2.3 The Goals of Service Composition in Ubiquitous Computing

- Context-awareness
  - Sensitive to context changes
- Managing contingencies
  - Devices—and thus services—often have unpredictable availability
- Leveraging heterogeneous devices
  - Ubiquitous computing systems use a variety of devices
- Empowering users
  - Users might compose or recompose applications according to their preferences

3. Interoperation

- How two or more components interoperate?
  - Communication protocols
  - Programming models
- Software interface compatibility
  - Allow interfaces to be heterogeneous, but adapt interfaces to one another
    - *(this approach is difficult)*
  - Constrain interfaces to be identical in syntax across as wide a class of components as possible
    - *(as much as possible)*
    - *UNIX pipe, HTTP methods: GET, POST, …*

3. Interoperation

- Three different support levels

Application contexts

Specific to an application domain

Communication mechanisms

Remote Procedure Call and its variations

Service location

network addresses

3.1 Data-Oriented Programming for Volatile Systems

- Data-oriented (or content-oriented)
  - Systems that use an **unvarying** service interface
    - *such as UNIX pipes and the Web*
- Enforce compatibility
  - Through standardized **data-type descriptors** supplied as metadata
  - Or by checking the **data values**

3.1 Data-Oriented Programming for Volatile Systems

- Two programming models for interoperation between indirectly associated components
  - Event systems
    - *Publishers publish events to subscribers*
  - Tuple spaces
    - *Fixed, generic interface to add and retrieve structured data called tuples*
    - *Example – camera software / hotel picture frame*

3.2 Indirect Associations and Soft State

- System volatility makes it undesirable to rely on a service provided by a particular component since that component could leave or fail at any time

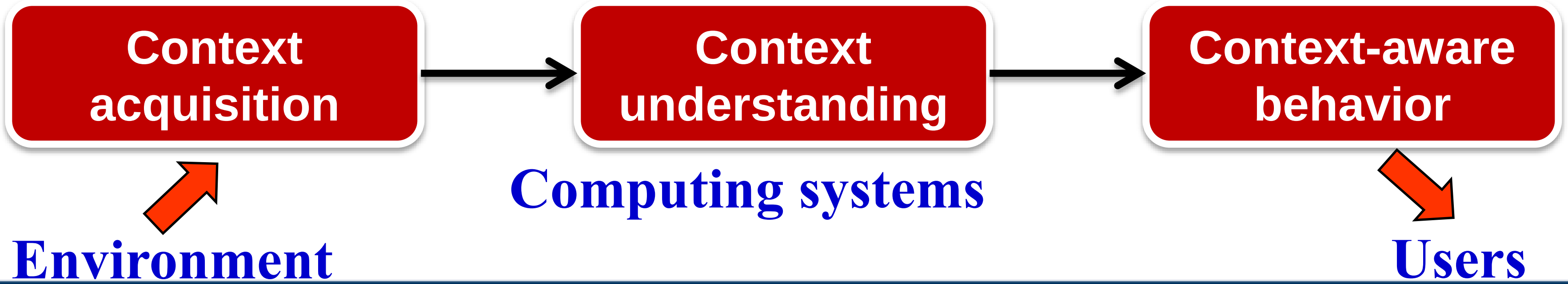
- Some of the examples of data-oriented programming systems involved indirect, anonymous association
  - Components that interoperate via an <u>event system</u> or <u>tuple space</u> do not necessarily know one another’s names or addresses
  - As long as the <u>event service</u> or the <u>tuple space</u> persist, the individual components can come and go and be replaced

4 Sensing and Context-Awareness

- Processing data collected from sensors
- Context-aware systems respond to sensed physical surroundings
- What is context?
  - By example
    - *Location, time, temperature, the identity of an associated users, the presence and state of an object, etc.*
  - By synonym
    - *Situation, environment, circumstance*
  - By definition
    - *The context of an entity (person, place, or thing) is an aspect of its physical circumstances of relevance to system behavior*

4.1 Context-Awareness

- A key concept in ubiquitous computing: deal with linking changes in the environment (physical world) with computing systems
  - Acquisition of context
  - Abstraction and understanding of context
  - Application behavior based on the recognized context
- Build intelligence about physical world in computing systems



4.2 Sensing Architectures

- Four functional challenges to be overcome in designing context-aware systems
  - Integration of idiosyncratic (peculiar) sensors
    - *Specialized knowledge to correctly deploy sensors in the physical scenario of interest*
  - Abstracting from sensor data
    - *Agreement on the meaning of contextual attributes, and software to infer those attributes from raw sensor values*
  - Sensor output may need to be combined
    - *Require output from sensors of different types in order to gather several contextual attributes that it needs to operate*
  - Context is dynamic
    - *Response to changes in context, and not simply to read a snapshot*

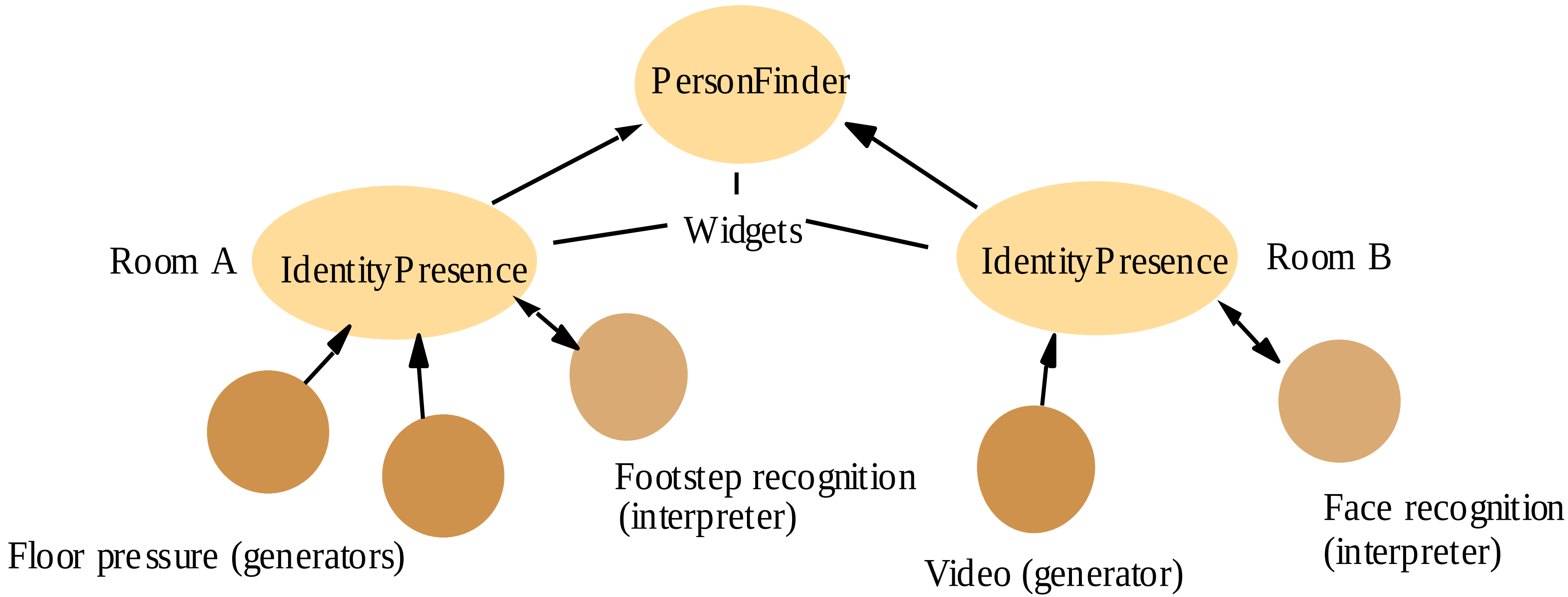
4.2 A General Context-Aware Application: The Context Toolkit

♦ The *IdentityPresence* Widget Class

Attributes (accessible by polling)	Explanation
Location	Location the widget is monitoring
Identity	ID of the last user sensed
Timestamp	Time of the last arrival
Callbacks	
PersonArrives(location, identity, timestamp)	Triggered when a user arrives
PersonLeaves(location, identity, timestamp)	Triggered when a user leaves

4.2 A General Context-Aware Application: The Context Toolkit

- A *PersonFinder* widget constructed using *IdentityPresence* widgets



4.2 Wireless Sensor Networks

- Large number of small, low-cost devices or nodes
- Each with facilities for sensing, computing and wireless communications
- Two main design requirements
  - Energy conservation
  - Continuous operation despite volatility
- Three main architectural features
  - In-network processing
  - Disruption-tolerant networking
  - Data-oriented programming models (e.g., directed diffusion)

4.3 Location-Sensing

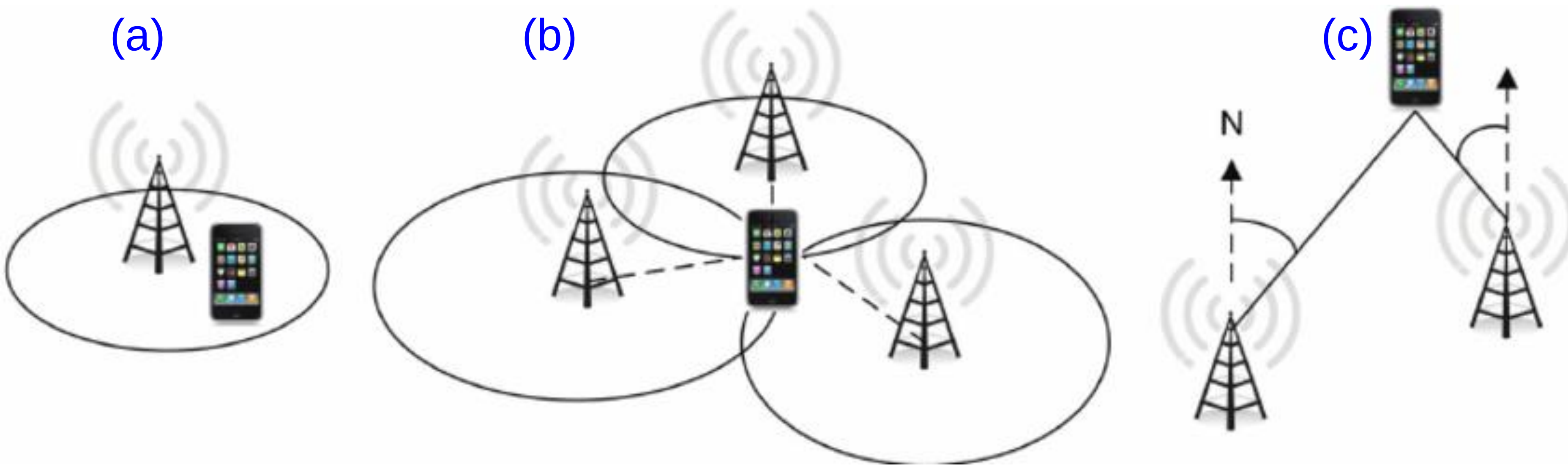
- Location is an obvious parameter for mobile, context-aware computing
- It is natural to make applications and devices behave in a way that depends on where the user is, such as the location-aware phone
- Location-sensing systems
  – Designed to obtain data about the position of entities (objects and humans) within some type of region of interest
  – E.g., Location sensing with scene analysis

4.3 More Location-Sensing Technologies

a) Proximity: within a small distance from device

b) Trilateration: distance measurements to device

c) Triangulation: angels relative to device



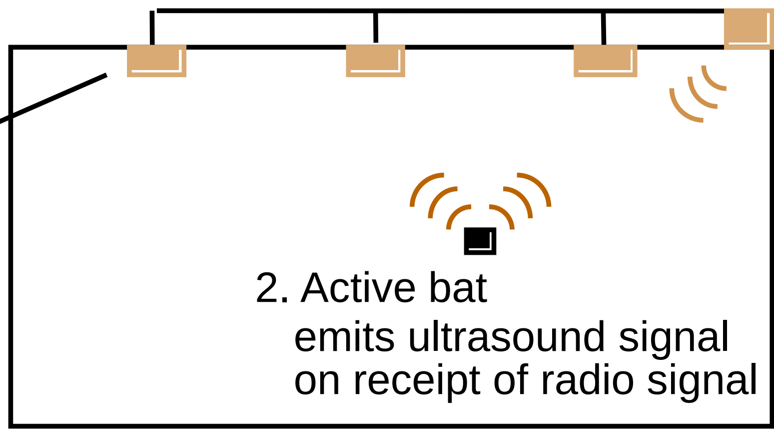
4.3 Some Location-Sensing Technologies

Type	*Mechanism*	*Limitations*	*Accuracy*	*Type of location data*	*Privacy*
GPS	Multilateration from satellite radio sources	Outdoors only (satellite visibility)	1–10m	Absolute geographic coordinates (latitude, longitude, altitude)	Yes
Radio Beaconing	Broadcasts from wireless base stations (GSM, 802.11, Bluetooth)	Areas with wireless coverage	10m–1km	Proximity to known entity (usually semantic)	Yes
Active Bat	Multilateration from radio and ultrasound	Ceiling mounted sensors	10cm	Relative (room) coordinates.	Bat identity disclosed
Ultra Wide Band	Multilateration from reception of radio pulses	Receiver in stallations	15cm	Relative (room) coordinates	Tag identity disclosed
Active Badge	Infrared sensing	Sunlight or fluorescent light	Room size	Proximity to known entity (usually semantic)	Badge identity disclosed
Automatic Identification Tag	RFID, Near Field Communication, Visual tag (e.g. barcode)	Reader installations	1cm–10m	Proximity to known entity (usually semantic)	Tag identity disclosed
Easy Living	Vision, triangulation	Camera installations	Variable	Relative (room) coordinates	No

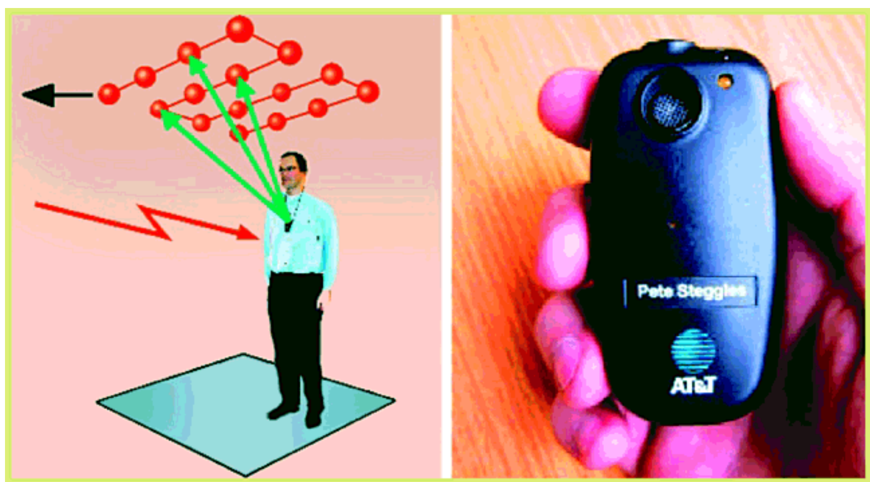
4.3 Locating an Active Bat within a Room

1. Base station sends timing signal to ultrasound receivers and radio signal to bat simultaneously

3. Ultrasound receivers report times of flight of ultrasound pulse

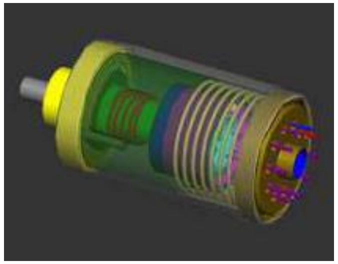


4. Base station computes distances to ultrasound receivers from times of flight, and thus position of bat



4.4 Modern Sensors for Contextual Values

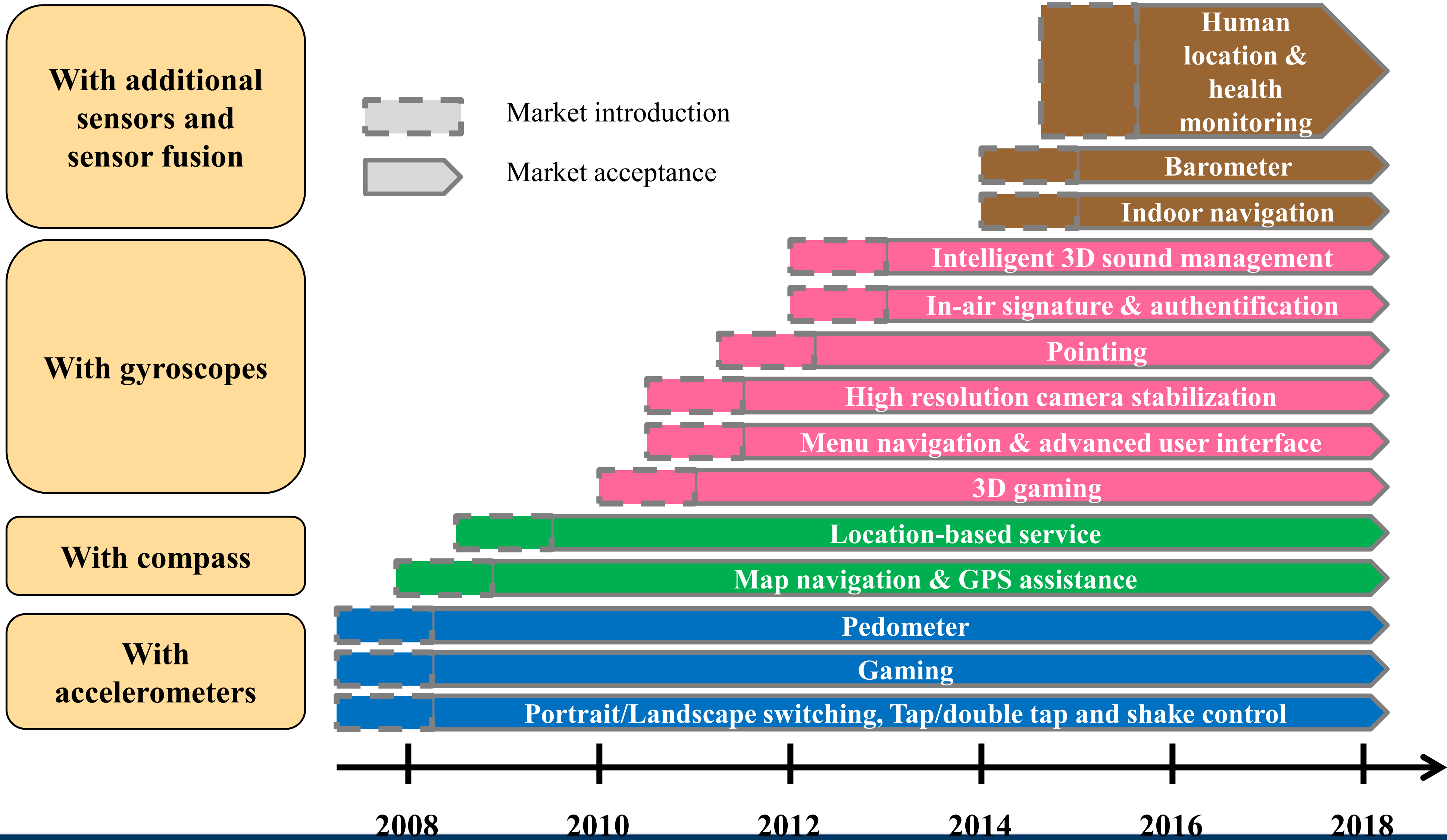
- Sensors are combinations of hardware and/or software used to measure contextual values
- Location, velocity and orientation
  - GPS
  - Accelerometer, gyroscope
  - Digital compass
- Ambient (surrounding, encompassing) conditions
  - Microphone
  - Camera, ambient light sensor
  - Proximity sensor
  - Barometer, humidity sensor, thermometer
- Presence
  - Devices that read electronic identifiers on tags brought near to them
  - Infrared readers used to sense active badges



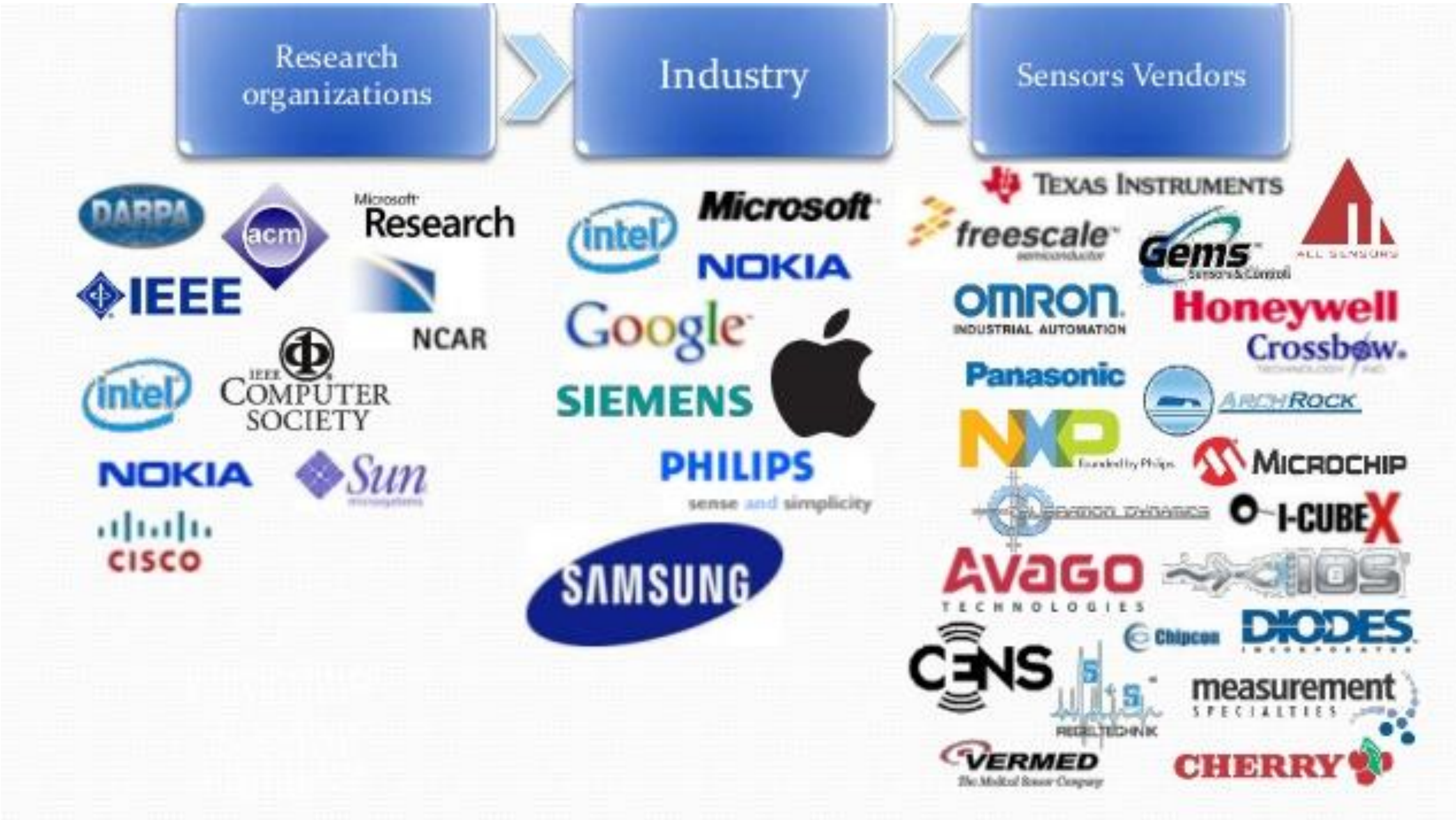
4.4 Sensors Are Becoming Ubiquitous

- 85% of mobile devices ship with GPS
- 50% of mobile devices ship with accelerometers and ~50% with gyroscopes
- Shipments of mobile motion sensors (accelerometers, compasses, gyroscopes, and pressure sensors) will reach USD 8.17B market by 2022.
- Contextual Computing will be a USD$125B market by 2024

4.4 Phone Functionalities Enabled by Sensors



4.4 Sensors and Context-Aware Solutions Are on the Market Already



5 Summary

- We presented the main challenges raised by mobile and ubiquitous computer systems
- We discussed aspects of volatility, some techniques for association components, and enabling them to interoperate despite the difficulties of “constant change”
- The integration of devices with physical world involves sensing and context awareness
- Read Reference Book Chapter 19