Part I Outline

- Module 1: Introduction to IoT
  - A Motivating Example
  - IoT Concept
  - IoT Trend
  - IoT Applications
  - IoT Application Enablers
  - IoT Challenges
- Module 2: General Network Architecture for IoT
  - IoT Network Architecture
  - 3-Layer Model: Functional Stack, Compute Stack
  - Cloud Computing
  - Communications with Cloud: HTTP, REST, CoAP, MQTT
- Module 3: IoT Devices
  - Sensors and Actuators
  - Connected Smart Objects
  - **IP as the IoT Network Layer**
  - Information Acquisition

IP as the IoT Network Layer

- Open and standards-based
- Versatile
- Ubiquitous
- Scalable
- Manageable and reasonably secure
- Stable and resilient

IP as the IoT Network Layer

Adoption or Adaptation of the Internet Protocol

- Adoption involves replacing all non-IP layers with their IP layer counterparts, simplifying the deployment model and operations
- Adaptation means application layered gateways (ALGs), acting as translaters, must be implemented to ensure the translation between non-IP and IP layers

IP as the IoT Network Layer

Adoption or Adaptation of the Internet Protocol

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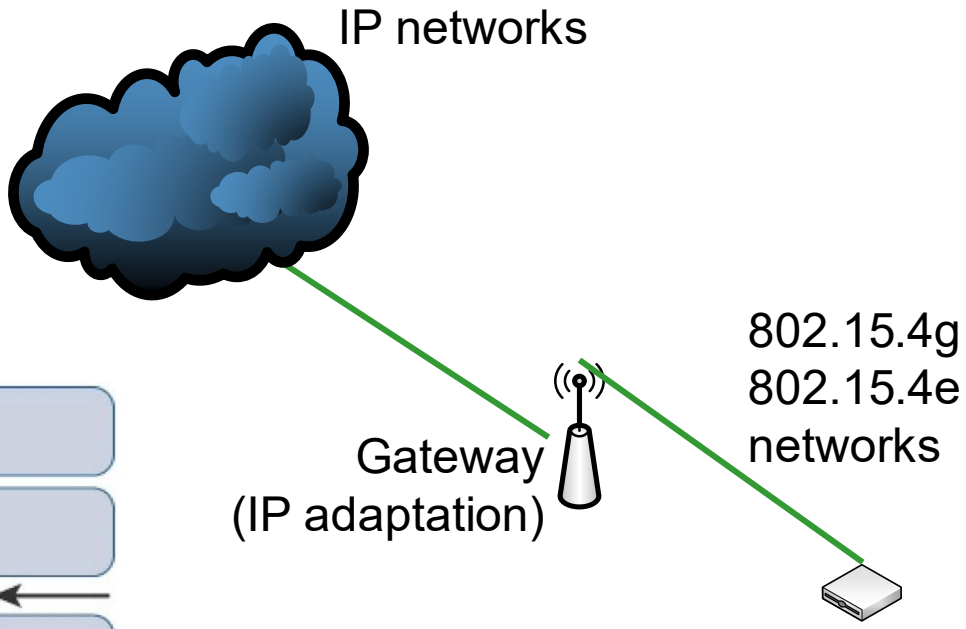

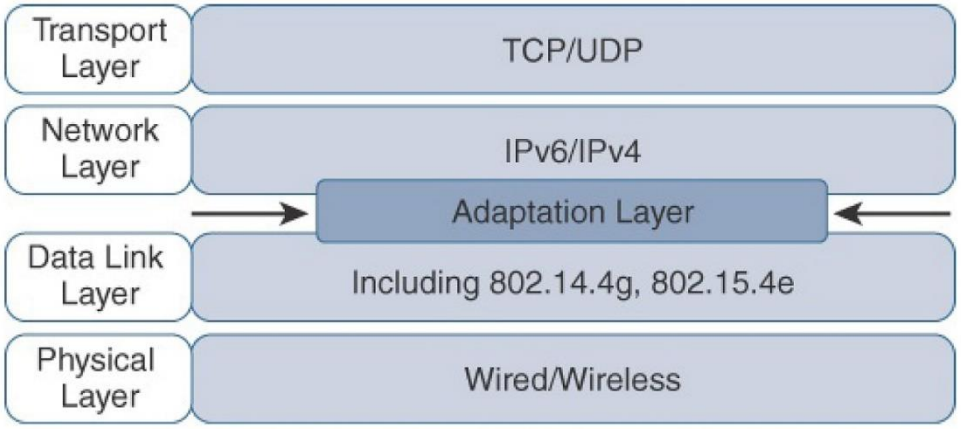

Figure 5-1 *Optimizing IP for IoT Using an Adaptation Layer*

IP as the IoT Network Layer

Adoption or Adaptation of the Internet Protocol

- Bidirectional versus unidirectional data flow
  - Transmitting only may not be necessarily worth implementing a full IP stack
- Overhead for last-mile communications paths
  - IP adoption incurs more overhead
- Data flow model
  - IP is suitable for end-to-end
- Network diversity
  - Dependency on single PHY and MAC layers for adaptation

IP as the IoT Network Layer

Adoption or Adaptation of the Internet Protocol

- Devices that are very constrained in resources
  - Adaptation model
- Devices with enough power and capacities to implement a stripped-down IP stack or non-IP stack
  - Adoption model
- Devices that are similar to generic PCs in terms of computing and power resources but have constrained networking capacities, such as bandwidth
  - Adoption model

IP as the IoT Network Layer

Summary

- IP protocol suite has been deployed in private and public networks over the past three decades, interconnecting billions of IP devices and users
- Architecture has proven to be highly flexible, and it has protected investments in many ways
- IP protocols and technologies, including addressing, address provisioning, QoS, transport, reliability, and so on, can be reused as is by IoT solutions
- IP may fall short is in scenarios where IoT devices are constrained nodes and/or connect to constrained networks
  - Adaptation layers

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  - **Information Acquisition**

Autonomy of Smart Objects

- Smart objects are able to **sense** the environment, **interpret** the environment, **self-configure**, **interact** with other objects and exchange information with people

Smart Refrigerator

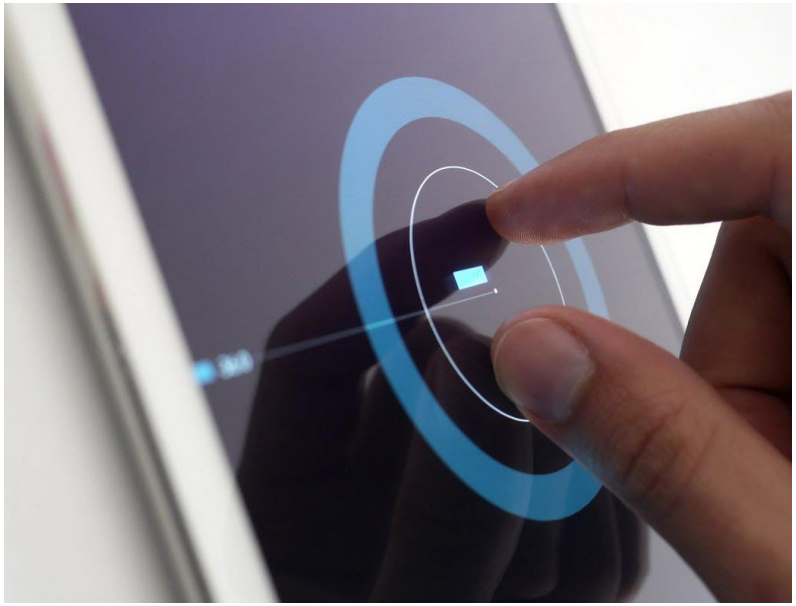
Categories of Information Acquisition

- Explicit user inputs via human-computer interactions (HCI)
- Context awareness

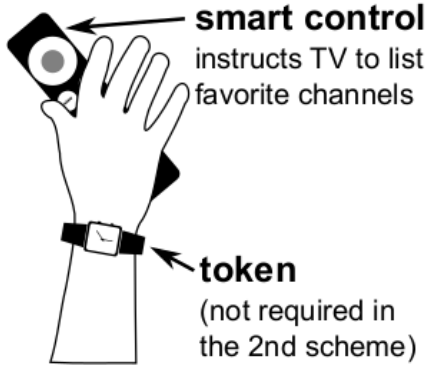
User Interfaces

- Types
  - **Keyboard/mouse/screen/speakers**
  - Pen input, touch
  - Speech/audio/sound
  - Gesture, eye movement
  - Virtual/augmented reality (VR, AR)
  - Wearable computing
  - **Multi-modal** interactive interfaces: more than just one input/output channel
- Considerations
  - Ease-to-use, flexible (error-tolerant), accurate, safe, privacy-preserving

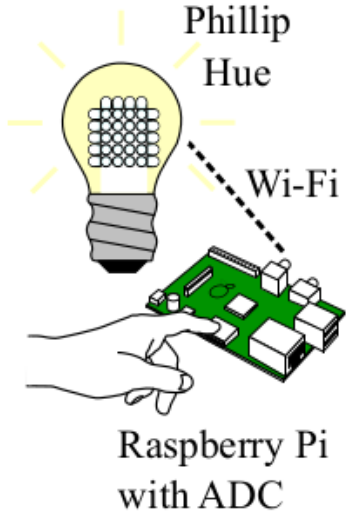
Touch as Input



Touch screen (a rich interface)



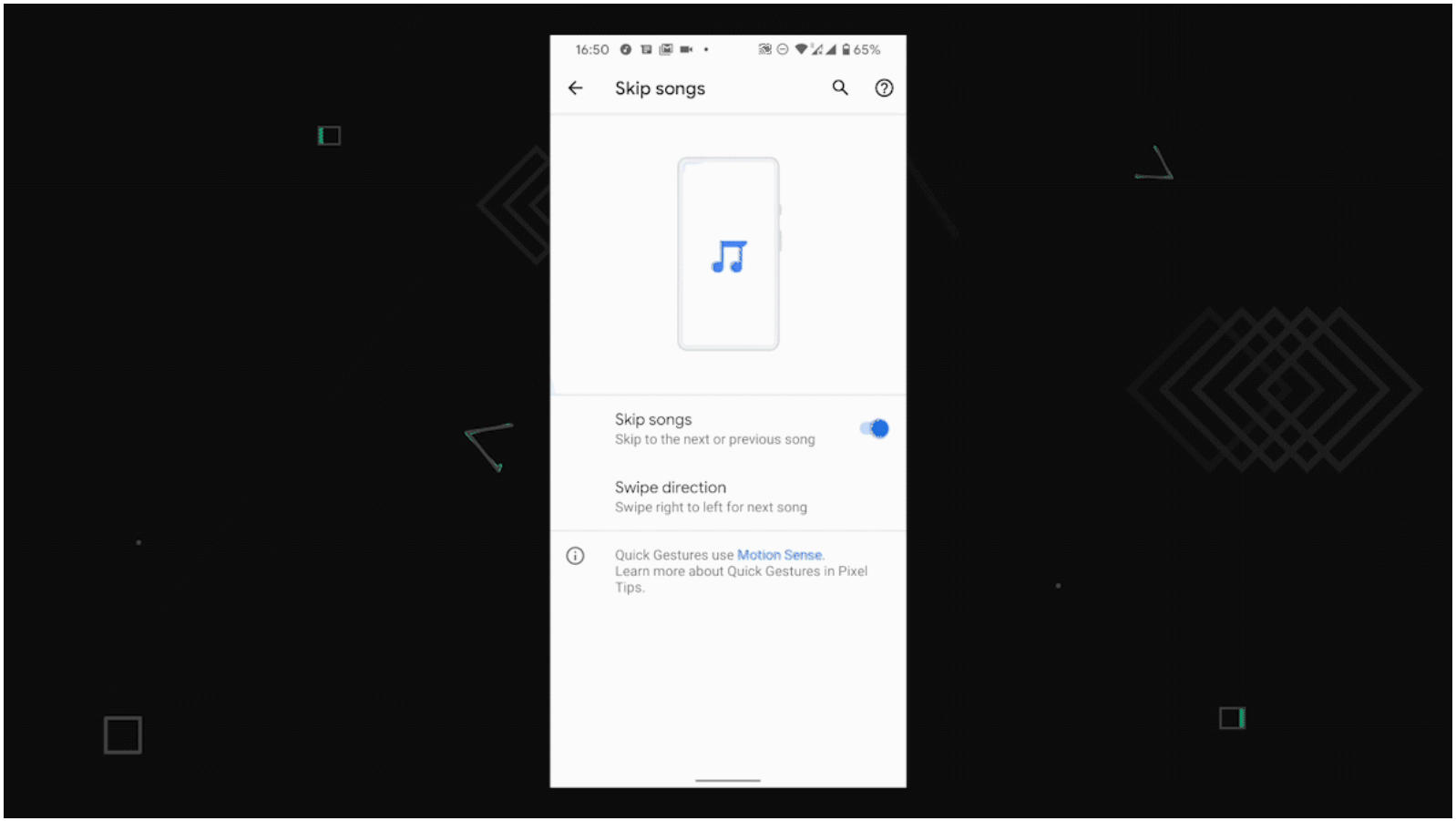
(a) Upon turning on a TV, the user's touch on the smart control personalizes the TV system to list the favorite channels.



(a) A smart light personalized by a finger touch.

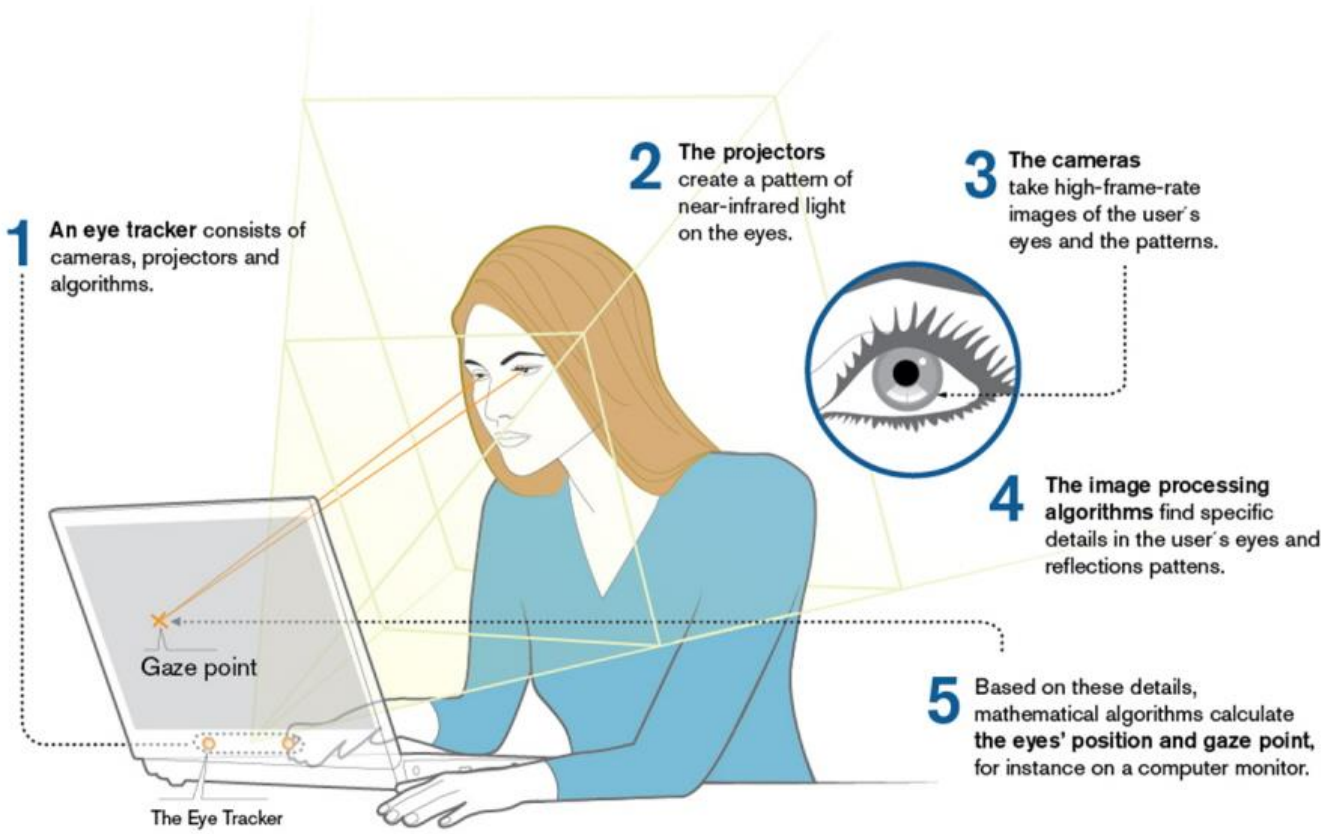
Interface-limited IoT devices
https://personal.ntu.edu.sg/tanrui/pub/mobicom022-yanA.pdf

Motion & Gesture Input

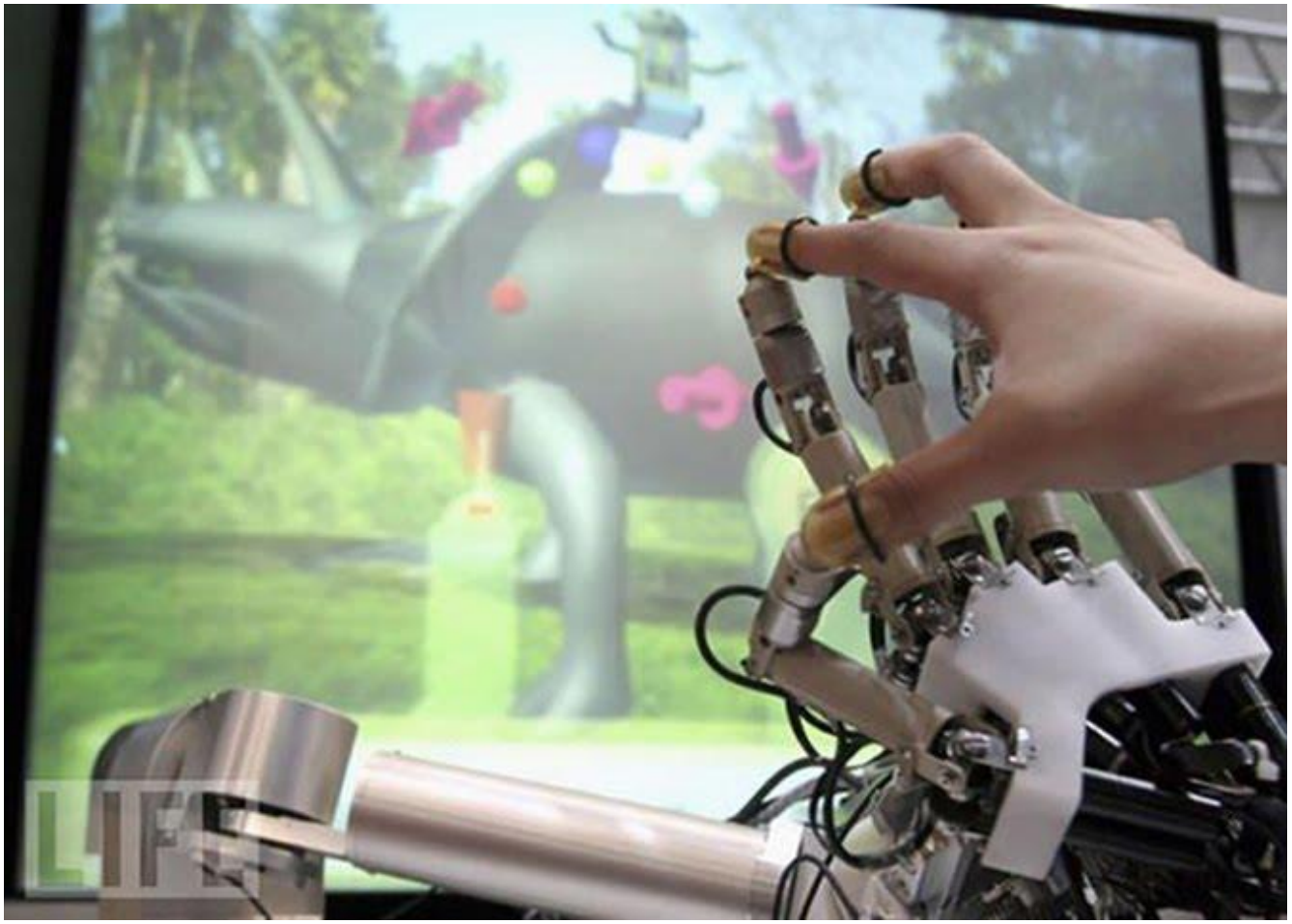


Google Pixel 4 has RADAR to perform hand motion and gesture sensing

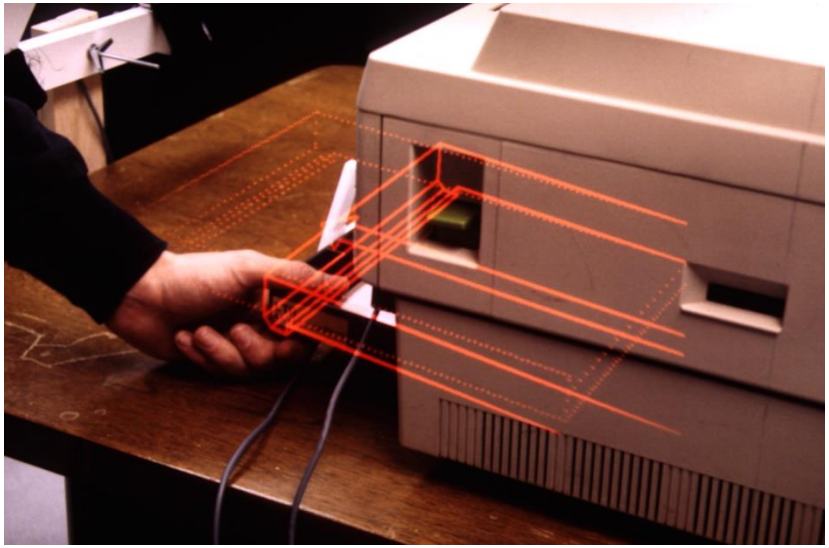
Eye Movement as Input



Haptic Interface



Augmented Reality



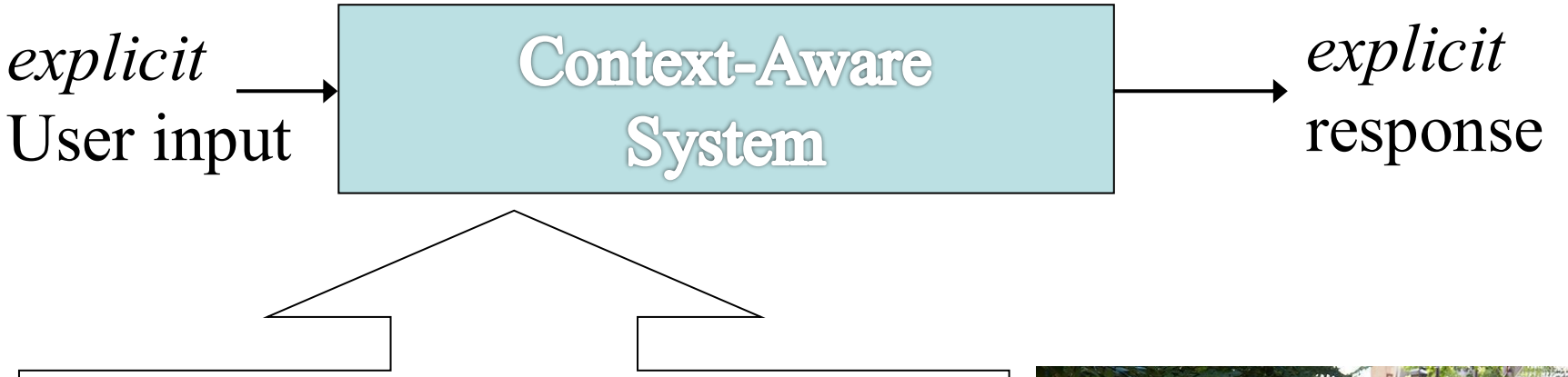
Speech Input

- Human beings have a great and natural mastery of speech
  - makes it difficult to appreciate the complexities
  - but it's an easy medium for communication

Windows Speech Recognition

- Supplied with every Windows machine
  - From ‘98 on
  - Almost no one used it
- What was the problem?
  - Need to “train” users to use early virtual assistants (VAs)
  - Microphone expense determines quality
  - No app buy-in

Context Sensing



Context:
- state of the user
- state of the physical environment
- state of the computing system
- history of user-computer interaction
- ...

Examples of Context

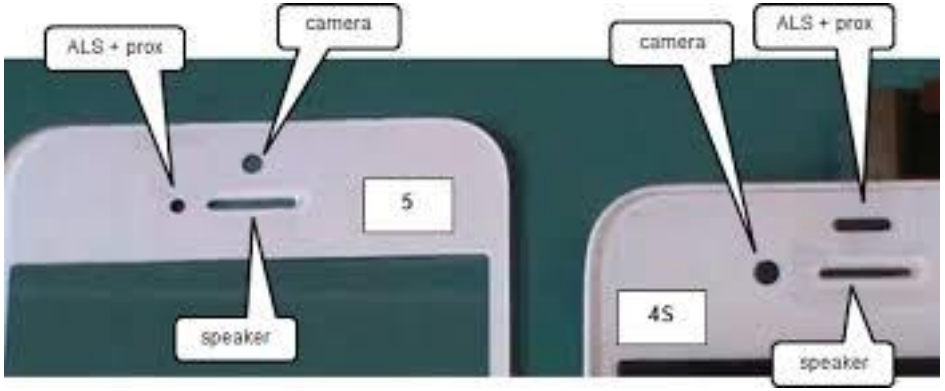
- Identity (user, others, objects)
- Location
- Date/Time
- Environment
- Emotional state
- Focus of attention
- Orientation
- User preferences
- Calendar (events)
- Browsing history
- Behavioral patterns
- Relationships (phonebook, call history)
- … the elements of the user's environment that the computer knows about…

Simple Everyday Examples

- Smartphone adjusts the screen to the orientation of the device
- Apple Watch turns on display if arm lifted/rotated
- Orientation is determined by using both a gyroscope and an accelerometer

Simple Everyday Examples (cont'd)

- Phone display adjusts the brightness of the display based on the surrounding area
- Uses a light sensor



Simple Everyday Examples (cont'd)

- Device disables touch screen when the user speaks on the phone
- Uses a proximity sensor (infrared signal travel time)

Simple Everyday Examples

- Device displays user's location, shows route to a desired destination, find nearby stores, geotag images on social media, etc.
- Outdoor: GPS
- Indoor: no one-fit-all solution
  3000+ PhD thesis?

- Tutorial topic
  Xiao et al., A Survey on Wireless Indoor Localization from the Device Perspective, ACM Computing Surveys, Vol. 49, No. 2, Article 25, June 2016 (31 pages)