Pervasive Computing and Communications

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Organization

- Motivation
- Pervasive Computing
- Services in pervasive environments
  - Modeling services
  - Service Composition
- PICO project at CSE@UTA
- SeSCo – Seamless Service Composition
- Applications
- Conclusions
- Ongoing and Future work – Possible Collaborations

Mark Weiser's prophecy

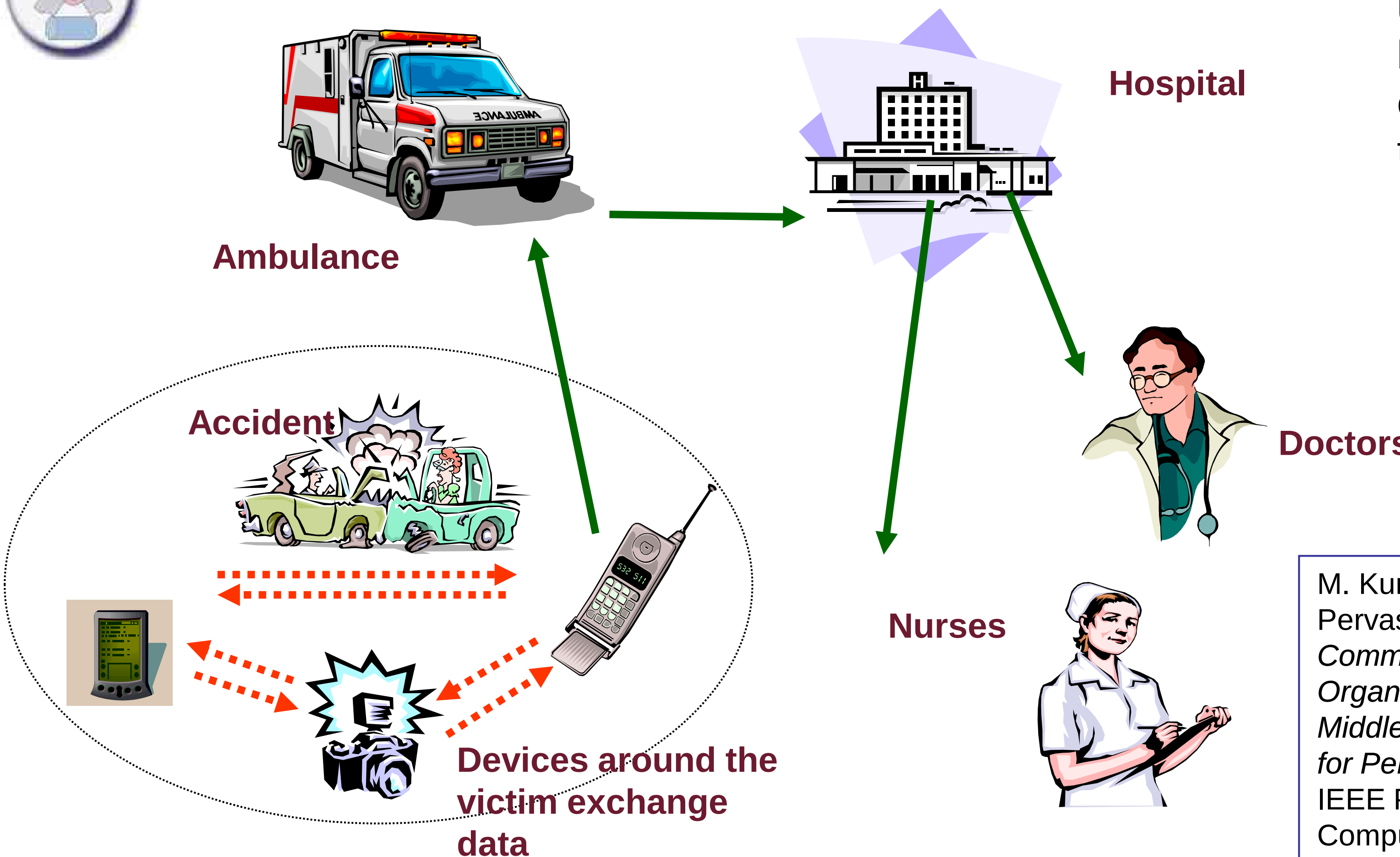
- "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it."

Mark Weiser, "The Computer for the Twenty-First Century," *Scientific American,* pp. 94-10, September 1991

Scenario

M. Kumar et al., Pervasive *Information Communities Organization PICO: A Middleware Framework for Pervasive Computing*, IEEE Pervasive Computing, July-September 2003, pp. 72-79.

Scenario



The scenario uses existing basic component technologies

Laptops, cameras, cell phones, PDAs etc.

M. Kumar et al., Pervasive *Information Communities Organization PICO: A Middleware Framework for Pervasive Computing*, IEEE Pervasive Computing, July-September 2003, pp. 72-79.

What makes these scenarios appear like fiction?

The whole is much greater than the sum of its parts

How can pervasive computing help?

- Desired actions
  - Detect and recognize events
  - Recognize high-level event
  - Discover and deploy services
  - Combine services
  - Match services to resources
  - Address dynamic issues
  - …
- On a TIMELY, AUTOMATED, TRANSPARENT basis
- Solution:

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Pervasive Computing: Challenges

- **Proactivity and transparency**
  - **Delays, resource utilization, unobtrusive services**
- **Heterogeneity and interoperability**
  - **Unevenness, incompatibility, h/w, s/w, communication channel**
- **Location awareness and mobility**
  - **Handoff- vertical/horizontal, data dissemination/acquisition**
- **Authentication and security**
  - **Privacy vs. services, cost, agents, active networks, availability**
- **Smart environments**
  - **Deployment, Interference**

M. Satyanarayanan, "Pervasive Computing: Vision and Challenges," IEEE Personal Computing, August 2001.

Enabling Technologies

- Networking Technologies
  - **Registration and Auto-configuration**
  - **Mobility management**
  - **Active networking**
  - **Wireless access**
- Computer Systems Technologies
  - **Distributed systems**
  - **Mobile computing**
  - **Software agents**
  - **Information acquisition and dissemination**
- Privacy, Trust, Authentication and Security
- Human-Computer Interfaces
  - Multi-modal
    - **Voice, touch, GUI, brain-waves, implied command,**

Middleware Services

- Glue heterogeneous entities
  - platform for interaction
- Match services to resources
  - Application specific
  - User profiles
- Combine resources and services
- Respond to user/application needs
- Mask unevenness
- Facilitate context-awareness
- Facilitate cooperation and collaboration

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Service Composition

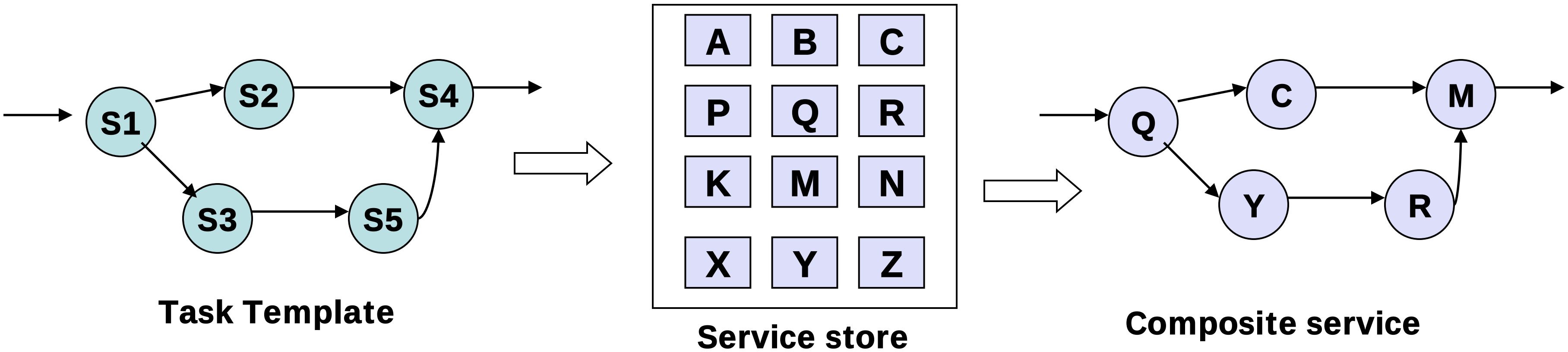
- Combining basic services into possibly complex services
- Typically works on the template matching principle
  - Requirements are specified in the form of a template
  - Runtime environment locates services that fit the place holders in the template
  - Coordination among identified services is performed by the runtime environment.
- Complex tasks can be broken down into subtasks
  - One template for each subtask
- Service discovery mechanisms available to locate available services
- Invocation of identified services
  - Event based
  - Process based
  - Task dependant

Service composition in pervasive computing

- Two types of composition mechanisms
- Static
  - Composition orchestrated prior to need
  - Capability to define finer interface dependency details
  - Ideal for stable, managed environments
  - Insufficient support for dynamism
- Dynamic
  - Composition formed once the request arises
  - Can consider the current context/service availability
  - Costly in terms of time for composition.

Current Work:
Research initiatives, no commercial implementations
Made to support systems, limited to pre-designed solutions
Service composition used as a *delivery vehicle* for applications.
Majority work on *discover* + *match* style

Service composition in pervasive computing:
Discover + Match



- Identify suitable services, mediate interactions, transactions among identified services
  - Spidernet[1], Reactive composition[2], Konark[3]
- Mostly variations of template matching schemes

[1] X.Gu, k. Nahrstedt, *"Dynamic QoS-aware multimedia service configuration in ubiquitous computing environments,"* 22nd International Conference on Distributed Computing Systems, 2002. Proceedings., 2-5 July 2002, Pages:311 – 318.

[2]] D. Chakraborty, F. Perich, A. Joshi, T. Finin, and Y. Yesha. "*A Reactive Service Composition Architecture for Pervasive Computing Environments,"* 7th Personal Wireless Communications Conference (PCW'2002), Singapore, 2002.

[3] S. Helal, N. Desai, V. Verma, and C. Lee, "Konark - a service discovery and deliveryprotocol for ad-hoc network," in Wireless Communications and Networking, 2003.WCNC 2003. 2003 IEEE, vol. 3, March 2003, pp. 2107 – 2113.

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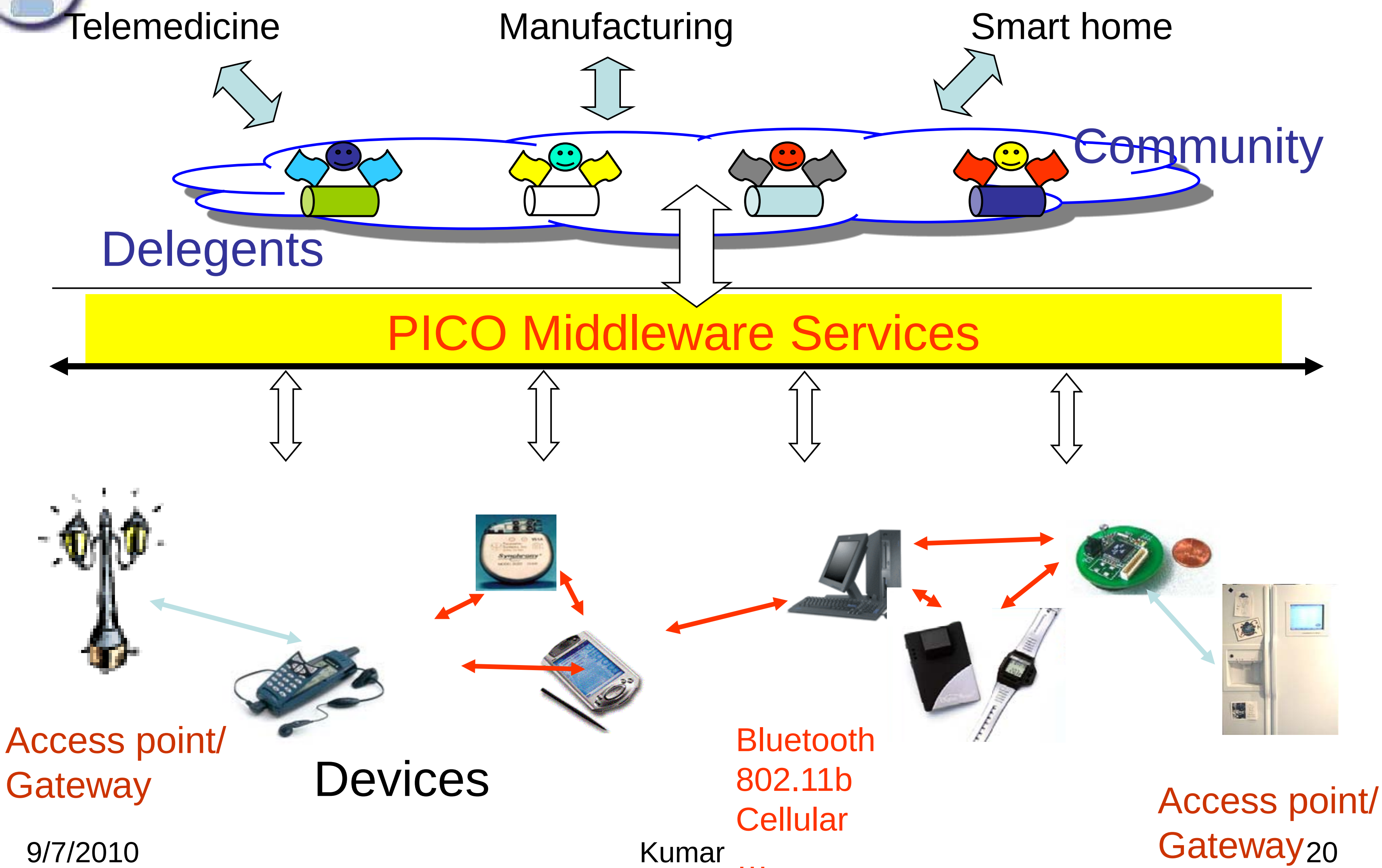
PICO Project at CSE@UTA

- Pervasive Information Community Organization
  - Provides transparent, automated services: *what you want, when you want, where you want, and how you want*.
- PICO is a framework to create mission-oriented dynamic computing communities of software agents that perform tasks on behalf of users and devices autonomously over existing heterogeneous network infrastructures, including the Internet.
- Propose concept of "COMMUNITY COMPUTING" to provide *continual*, *dynamic*, *automated* and *transparent* services to users.

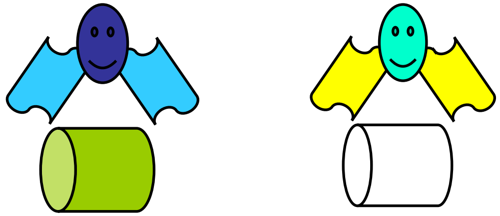
PICO Architecture



Basic Building Blocks of PICO

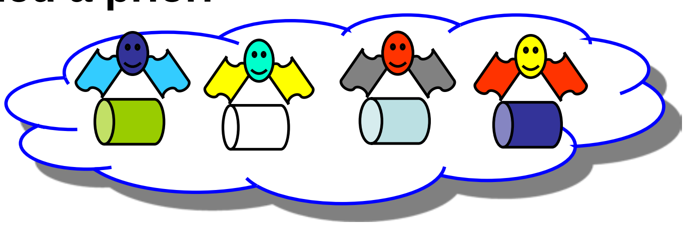
- Physical devices –
  - Computer-enabled devices: small, wearable to large supercomputer
  - Sensing capabilities
  - Computational power
  - Communication capability
  - Actuators

- Software entities – Delegents (Intelligent Delegate)
  - Intelligent SW agents – service provisioning
  - Proxy-capable: exist on the infrastructure
  - Event-driven
  - Execute on host devices
  - Need a host for execution
  - Mobile, capable of communicating



Community Computing: PICO based middleware

- **Formation of Computing Communities**
  - Community – Set of collaborating delegents
  - Service provisioning
    - **Programmed/scheduled**
    - **Continuous services**
  - Dynamic
    - **Membership and community defined a priori**
    - **Goal-driven**
    - **Dynamically formed**
    - **Dynamically dismantled**
  - Dynamically formed based on events



Devices

Devices

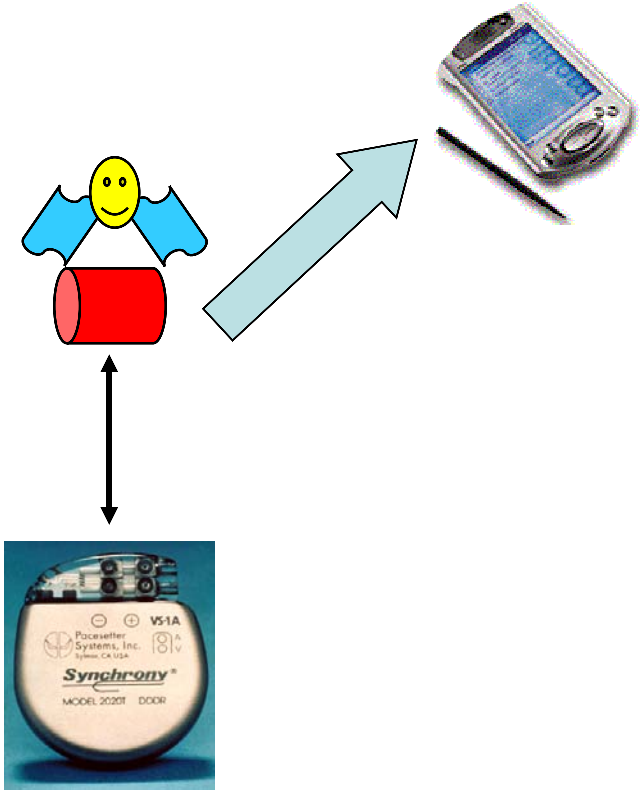
- $C = < C_{ID}, S, F >$
  - C_{ID}: Device identifier
  - S: System characteristics
  - F_c: Functionality of device
- For example, C = Heart Monitor
  - *S = <operating system; processor type; memory; I/O type; battery; wireless transceiver >*
  - *F = <ECG monitoring; processing; communicating>*

Delegents

- Intelligent Delegate: works diligently on behalf of a camileun, user, application or service
- $D = < D_{id}, F_d >$
  - D_{id}: Delegent ID: $< Id, C, P >$
    - ***Id*: Delegent ID**
    - ***C*: Host Device ID**
    - ***P*: Community**
  - F_d: Functionality of delegent: $< M, R, S >$
    - ***M*: Program modules**
    - ***R*: Delegent rules**
    - ***S*: Delegent services**

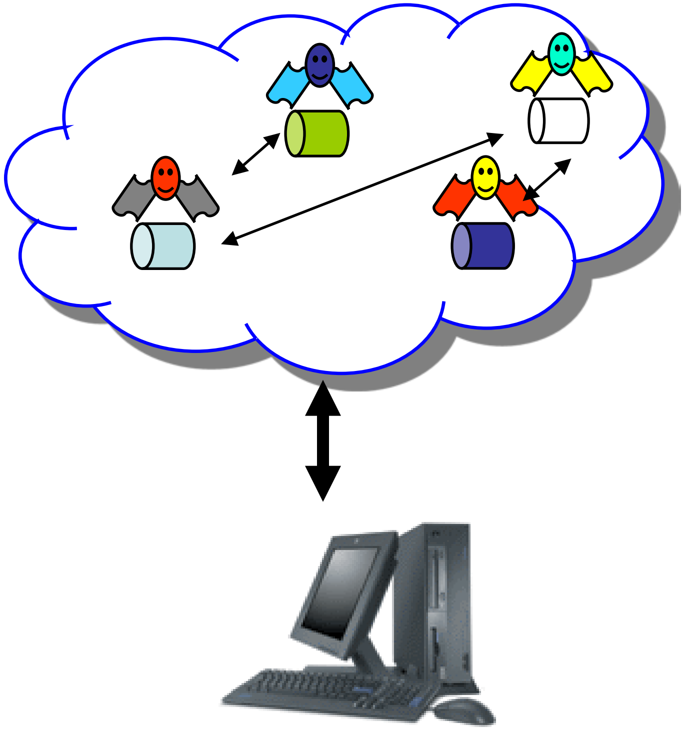
Delegent Example

- A Delegent for ECG monitoring
  - Functionality: < *Modules, Rules, Goals*>
  - **Modules**: Signal processing module, Arrhythmia detector, Software filter, Timer, Communication module.
  - **Rules**: State transitions, Migration rules, Communication rules, Community engagement rules.
  - **Services**: Detect arrhythmia, Upload ECG window, Communicate status.



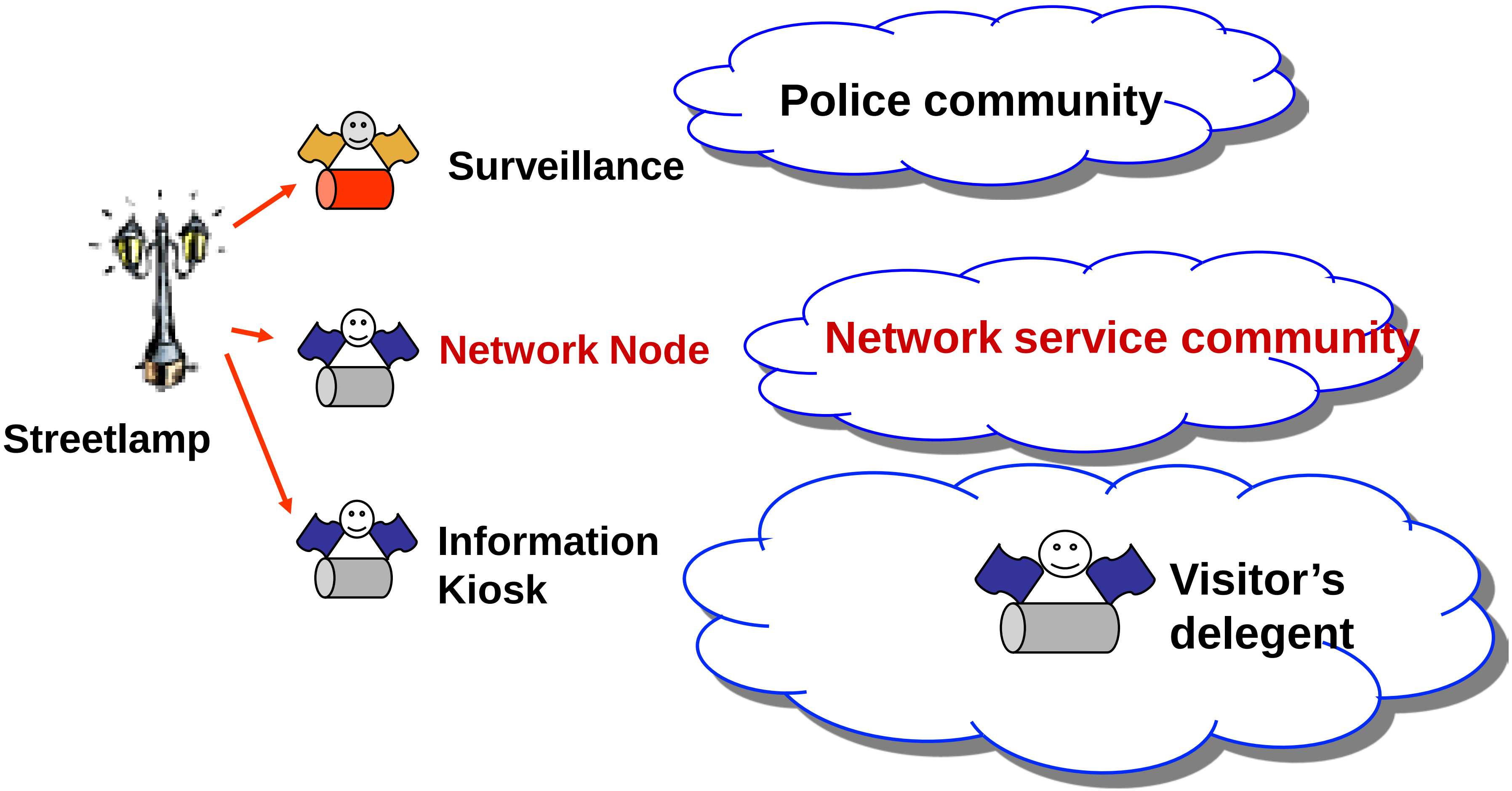
Community

- A community is defined by P = <*U, G, E*>
  - U: set of delegents in the community.
  - G: community goal(s).
  - E: community characteristics.
    - **Community ID**
    - **Number of delegents**
    - **Community coordinator/manager**
      - *Joining/disjoining of delegents*
      - *Location awareness and other services*
    - **Community of delegents need resources**
      - *CPU, Memory, Bandwidth*



CPU, Memory, I/O

Devices + Delegents = Services on Resources



PICO : Recap

- A middleware framework aimed at providing transparent, automated support to users
  - Creates a transparent platform over heterogeneous devices.
  - Device features and specific software functionalities exported as services
  - Creation of *communities* of software agents to support mission critical tasks.
  - Event oriented operation
- Three basic constructs
  - Devices ($C = <D_{id}, H, F>$)
  - Delegents ($D = <D_{id}, M, R, S>$)
  - Communities ($P = <P_{id}, U, G, E>$)

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S. Kalasapur, M. Kumar and B. Shirazi, Seamless Service Composition in Pervasive Environments, IEEE Transactions on Parallel and Distributed Computing, In Press.

Service model

- Each service is treated as a transformational unit, accepting a set of inputs and producing a set of outputs
  - Derived from the state machine representing delegent operation
- Each service faithfully works towards its desired goal
  - Assumption -- there are no malicious services
  - Security and trust schemes need to be employed to enhance the model
- Services are represented using a directed, attributed graph
- Each service has a set of *attributes* associated
  - Each service is described using both semantic and syntactic attributes

Service model

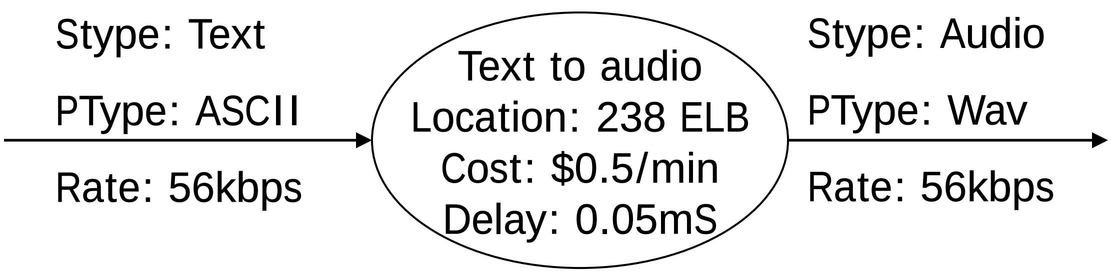
- Each service is represented by

$$G_S = \{V_s, E_s, \mu_s, \xi_s\}$$

Vs → node (s) representing service (or the state machine for the service)
Es → Edges to and from the service (I/O).
μ_s → Vertex attribute function.
  - *Service Name, location, address, cost, etc.*

ξ_s → *Edge attribute function*
  - *Type and size of parameters and messages*

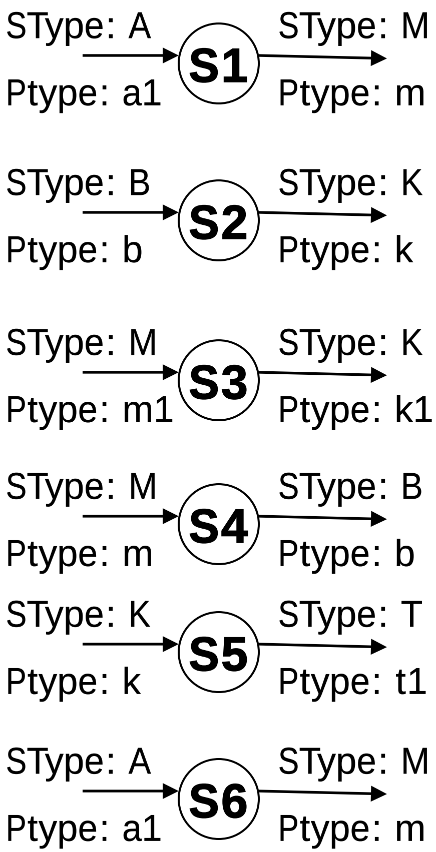
- *Attributes can also contain semantic descriptions of entities.*



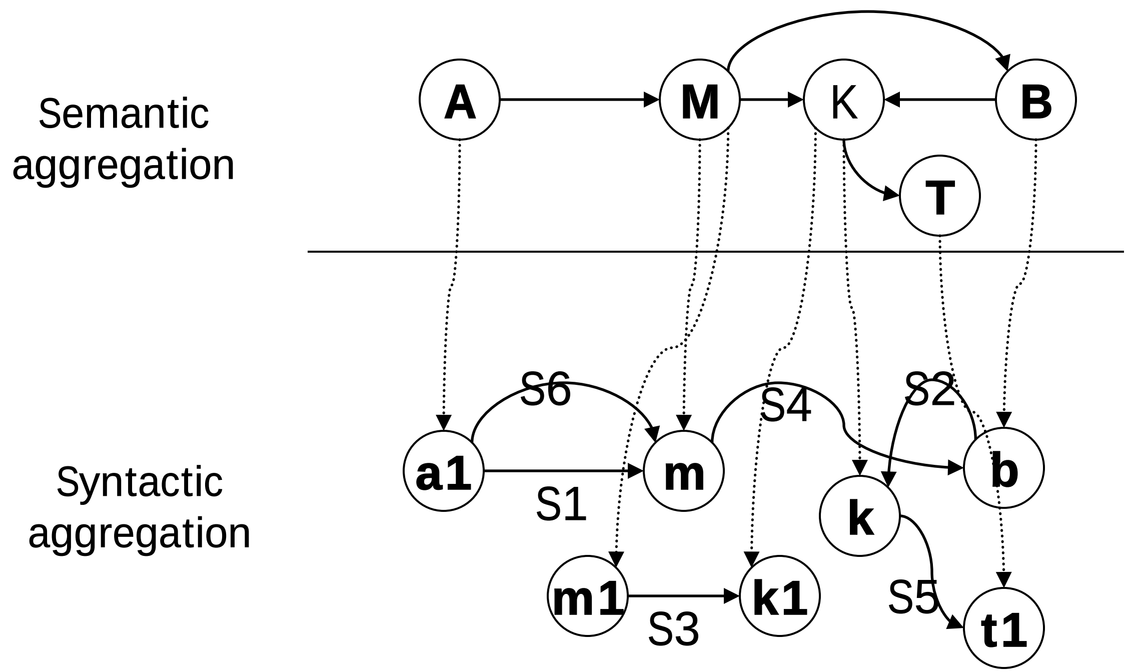
Service aggregation at the directory

- Aggregation based on the transformation achieved by each node
- Stored as a two-layered directed, attributed graph
  - First layer stores semantic transformations
  - Second layer stores syntactic transformations
- At the second layer, each available service is represented using a directed edge between the parameters it transforms

Service aggregation at the directory



Service graphs



Aggregation of services (G_P)

Task specification

- Each task/request represented as $G_R = \{V_r, E_r, \mu_r, \xi_r\}$

  Vr → Vertex set representing individual services required

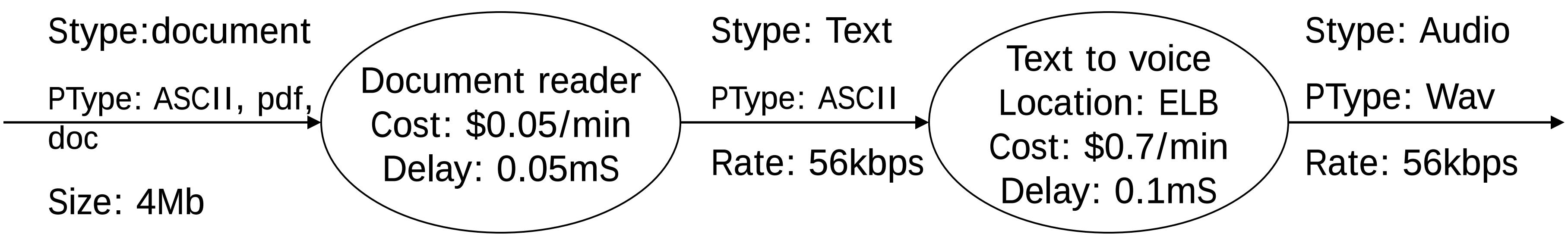
  Er → directed edge set representing interactions among the requested services

  μ_r → vertex attribute function

  – Service name, allowable cost, required bandwidth, permissible delay, etc,

  ξ_r → Edge attribute function

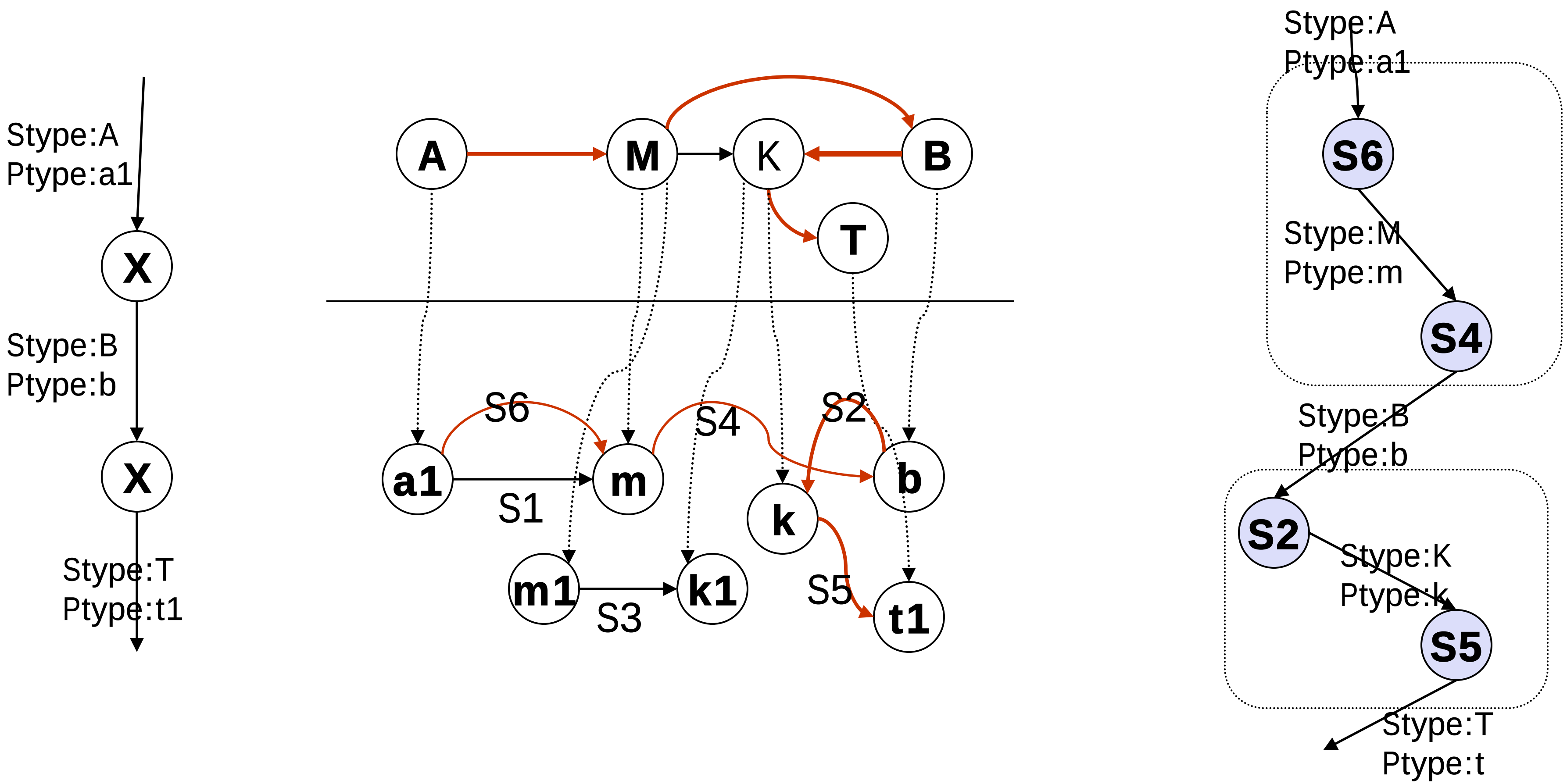
  – Details about exchanged messages such as size, expected format, data rate, etc.



Task resolution

- Each request (*GR*) consists of a number of services that need to be identified
- Consider each node, and its I/O types
  - Semantic and syntactic representations
- Look for a path in the semantic aggregation
  - If a path exists, composition possible
  - Locate the shortest path (k shortest paths)
- Locate corresponding paths in the syntactic aggregation
  - Weights defined by user preferences, quality parameters, cost, etc., as attributes of G_R
- Perform the procedure for all nodes in G_R

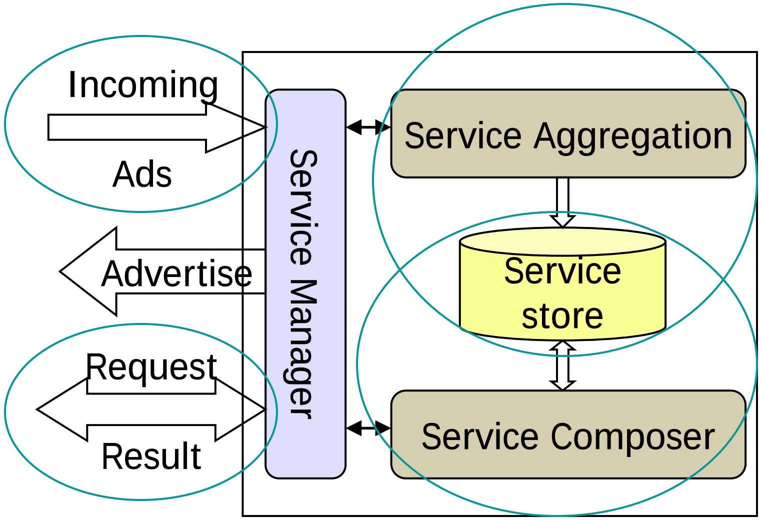
Task resolution



Service aggregation process

(Centralized scheme, managed networks)

- Well known directory structure
  - Services register at the directory
  - Directory maintains all available services by aggregating them
- Directory acts as the point of contact for task support
- Service composition performed at the directory
  - Execution of composition left to the client



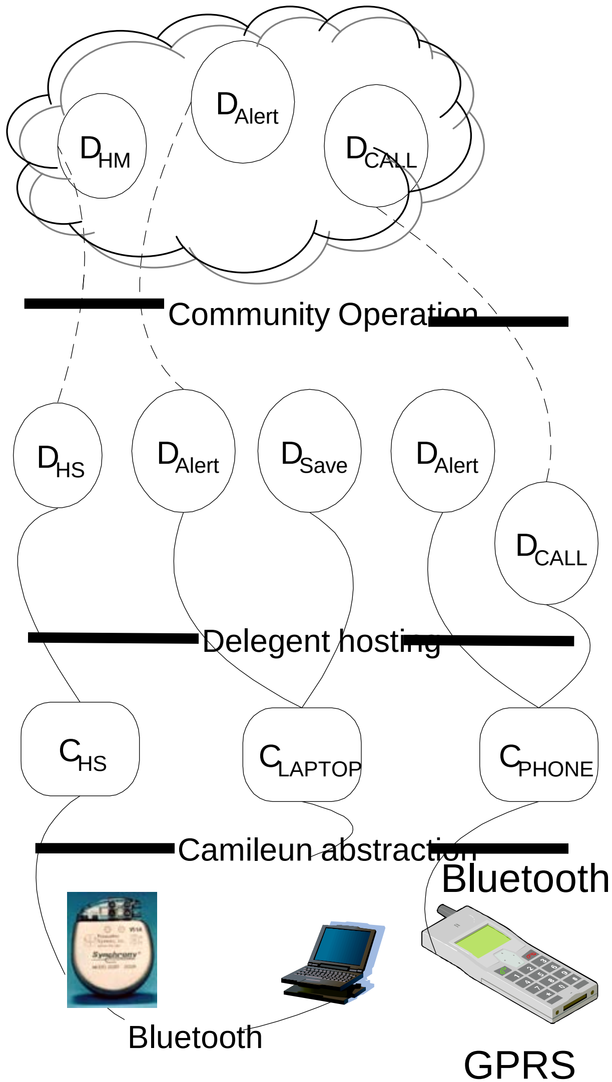
PICO Abstractions

High level complex services

Manifestation of resources as services

Device Abstractions

Devices



P = < U, G, E >
U = {voice capture (-->(c)), Alert, Call contact, file system}
G = {auto phone, file browse, file save}
E = {phonebook, 30sec data...}

$$P=<U,G,E>$$
$$\forall u_i \in U, \ni s_j \in S(D) \mid u_i \approx s_j$$

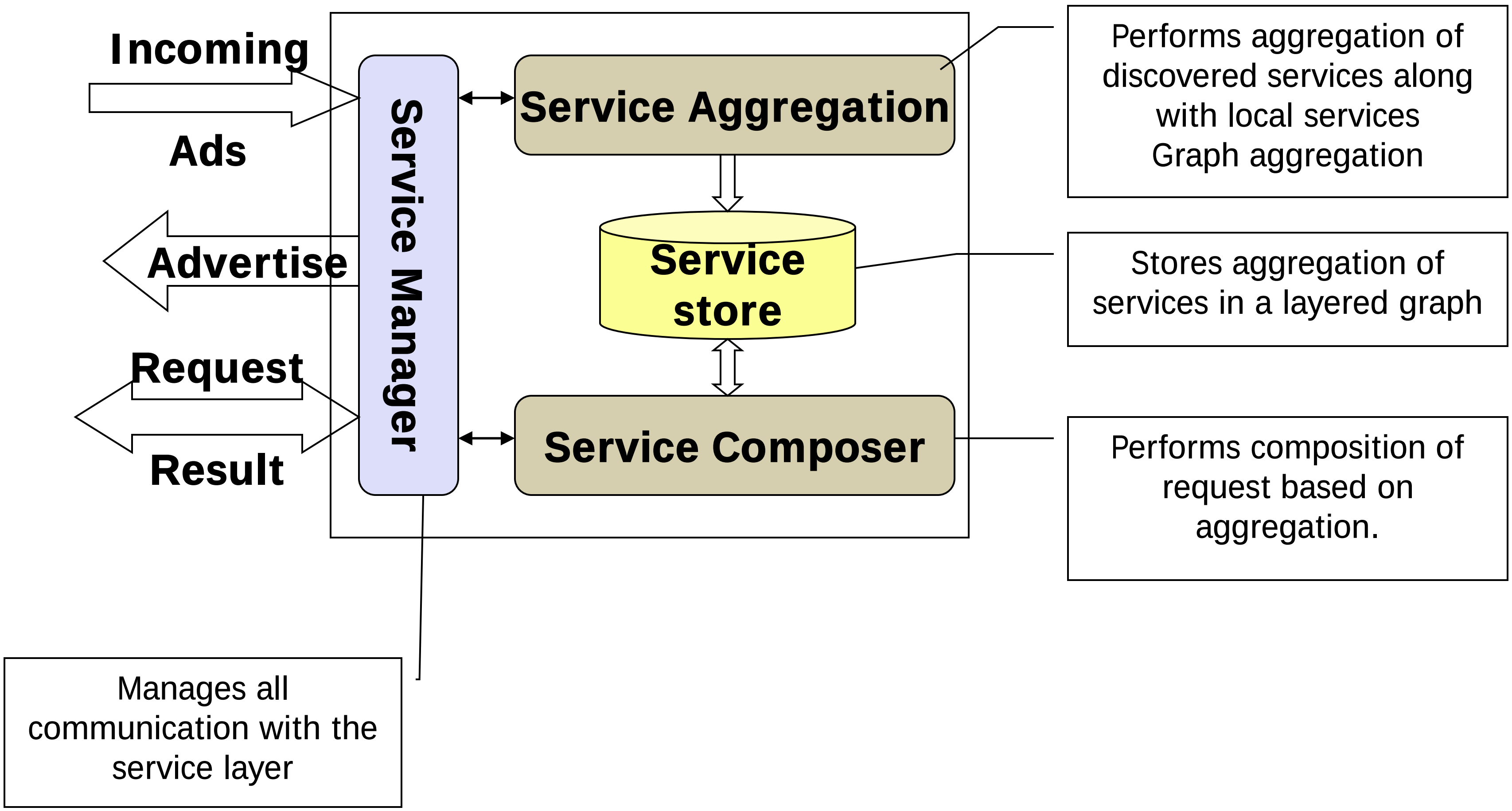
D = <M , R, S>
M_{Hs} = <sample voice, send voice, render voice (-->(b)) >
R_{HM}={E = "sample voice", C="sample ready" A = "render voice" }
S = {audioOut, voice capture} (-->(a), (c))

$$D=<M,R,S>$$
$$\forall m_i \in M(D), \ni h_i \in H(C) \mid req(m_i) \approx_i$$
$$\ni s_i \in S(D) \mid s_i \text{"projects"} f_j \in F(C)$$

$$C=<H,F>$$
$$\forall d_i \text{"installed on"} C_j, \ni H(C) \mid M\{d_i\} \approx \{H\}$$

C = <H,F>
$C_{Headset}$= <$H_{Headset}$, $F_{Headset}$>
H_{HM}{mem = 3MB, power_level = normal, communication = bluetooth (-->(b))}
F_{HM}={audible voice, capture voice}

Service Layer



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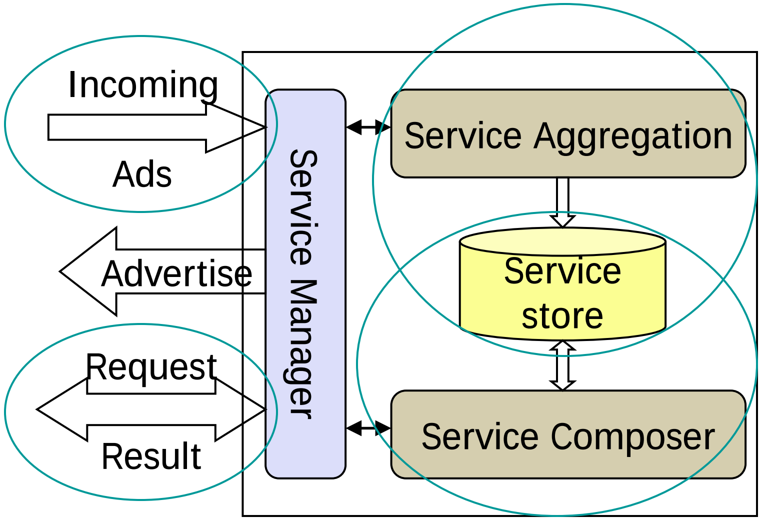


Centralized scheme: *limitations*

- Ideal to build and operate Service Provider communities, managed infrastructures
- Directory structure can be distributed, but all requests need to be resolved at the directory
- Ideal to build SOAs around assets in the infrastructure
  - Managed service definitions
  - Managed resources, therefore managed directory
  - Access to different resources can be controlled
- Directory node becomes the bottleneck

  - No explicit support for heterogeneous resources
  - No explicit support for dynamisms

Seamless service composition (SeSCo)

- Main Motivation
  - Resource heterogeneity to be actively exploited
  - Resource poor devices need to be proactively supported by their resource rich counterparts
- **User centric solutions**
  - **'What , where, and how' type of services**
  - **Dynamisms associated with user mobility**
  - **Quality of composed service**

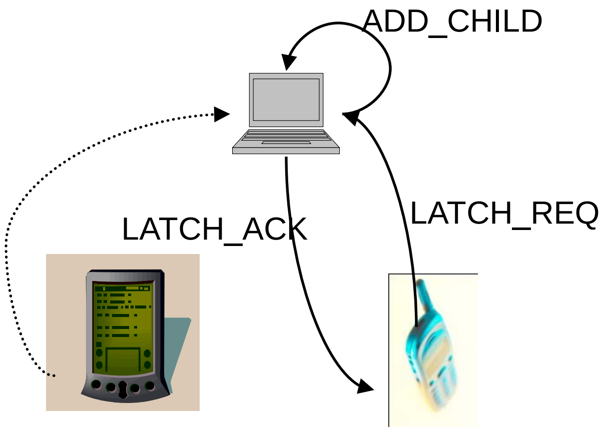
Device classification chart

Level (α)	Middleware version	Features	Examples
0	None	Features exported through delegents on Level-2 or Level-3 devices, No native personalization support	sensors, Legacy printers
1	Minimum	Community member, can not be a proxy, possibly mobile	Cell phone, mote sensors, smart printer
2	Complete	Community member, leader, Can act as a proxy, possibly mobile, Rsource rich	Laptop, PDA
3	Complete	Community member, leader, Can act as a proxy, Rsource rich, typically resides in the infrastructure, managed	PC, Server, Grid, cluster

Creating the hierarchy

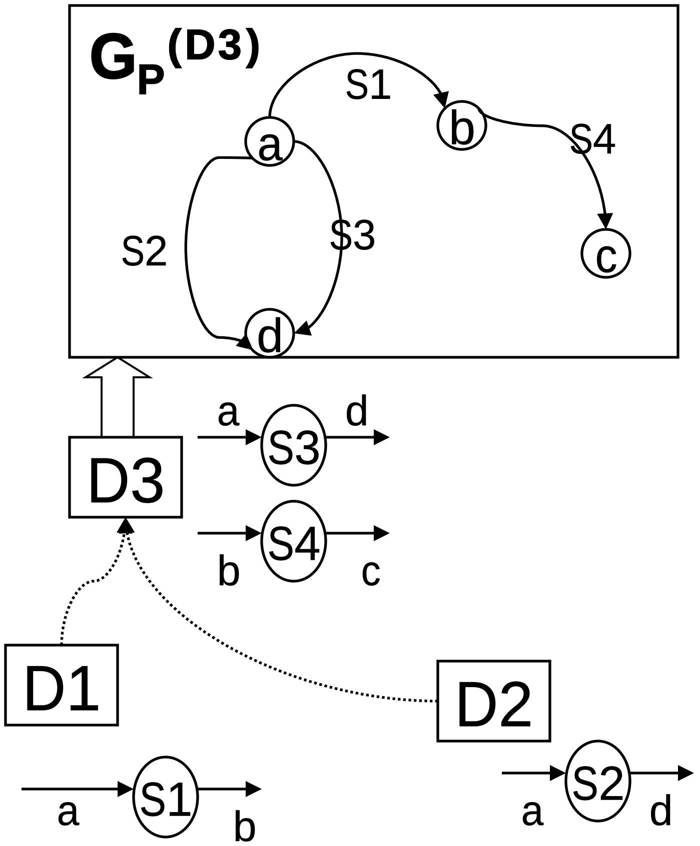
The LATCH protocol

- Devices lower in the hierarchy *latch* onto those higher in the hierarchy
- Service related information (Service graphs) exchanged during hierarchy creation
- Staged aggregation for improved composition support.
- Status changes reflected through periodic updates.



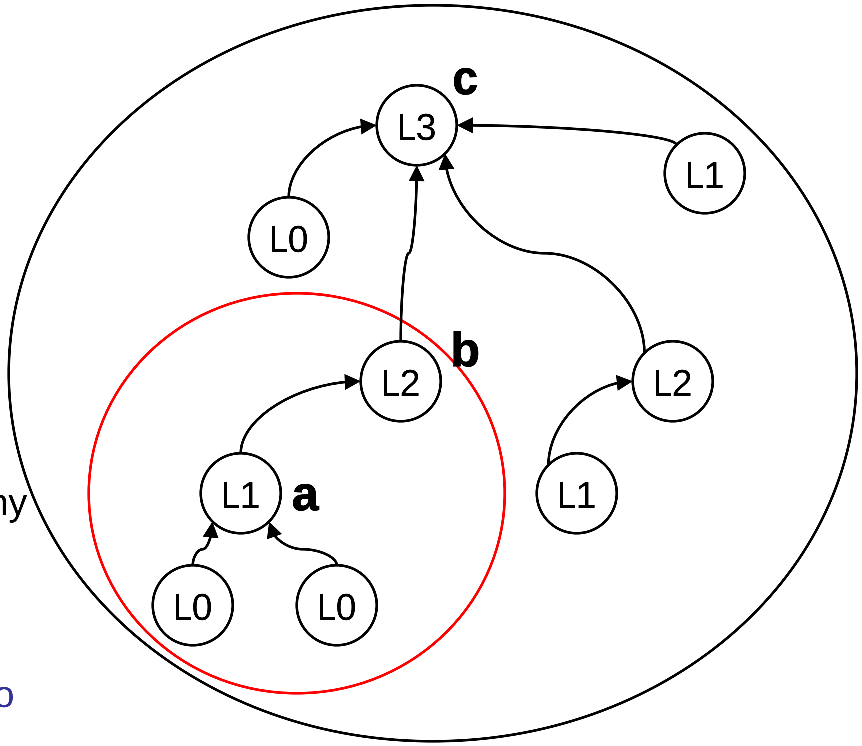
Hierarchical service aggregation

- Devices at each level in the hierarchy *aggregate* all services from that part of the hierarchy
  - Includes services available on the local device
  - Plus the services available at all descendent nodes



Properties of the overlay

- Service zone
  - All the services that a device is *responsible* for
- Search zone
  - All devices where a possible *match* is searched for



Requests resolved by propagation through the hierarchy

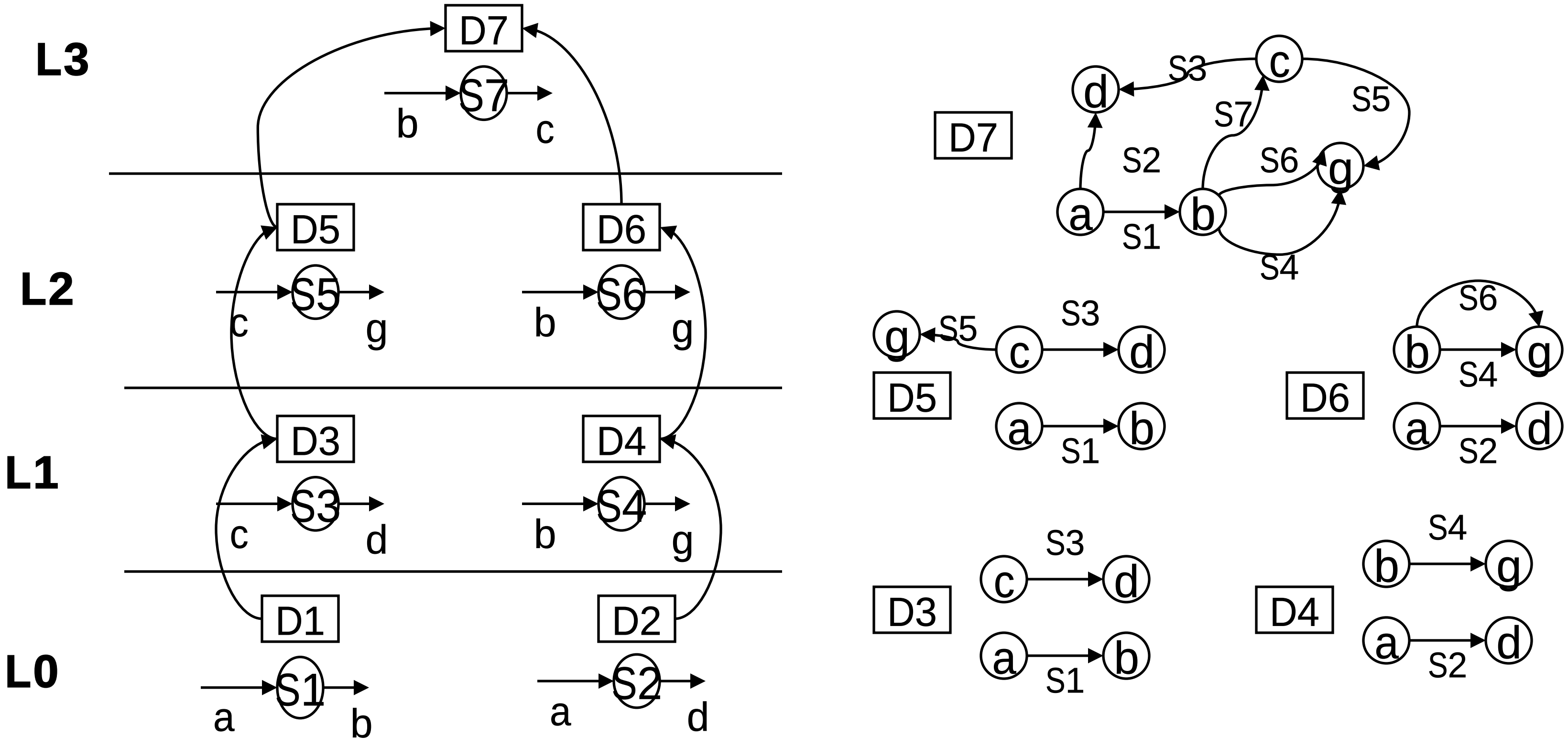
Search zone is *expanded* Incrementally

Partial composition is computed at each expansion

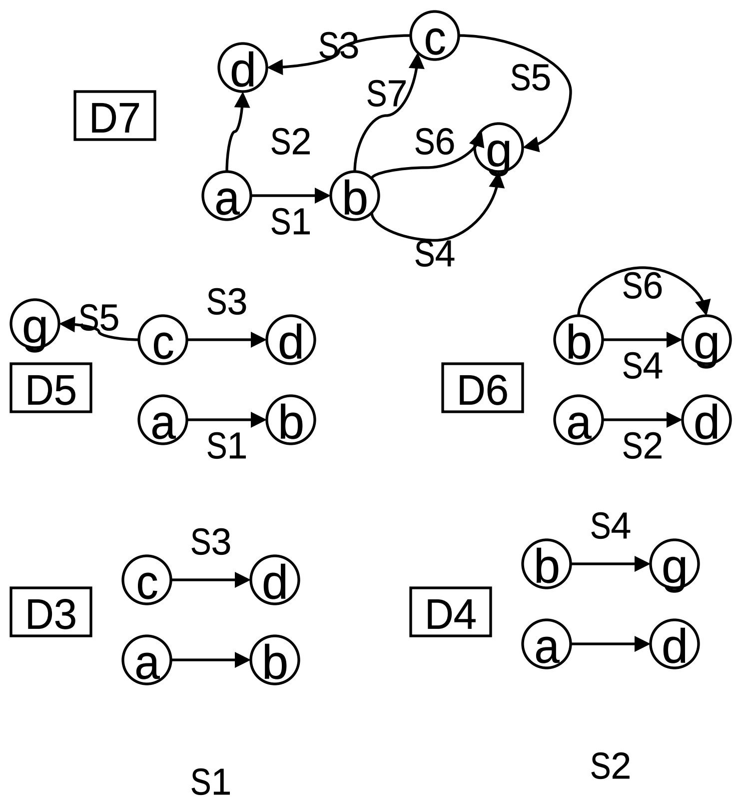
Unresolved parts of the requests are forwarded to the parent node

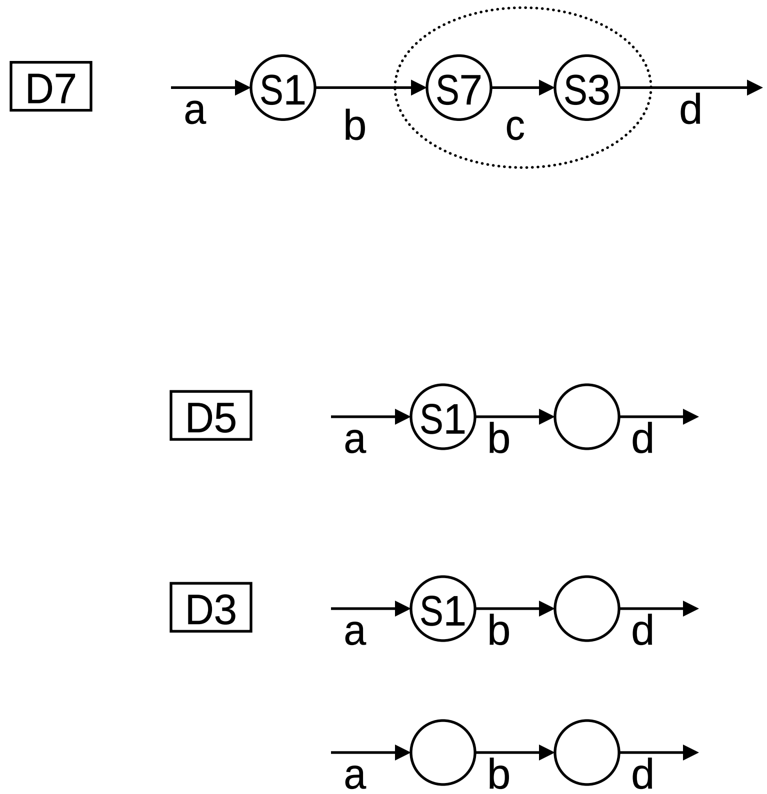
Compositions in the *local service zone* handled by the local node.

Hierarchical service composition



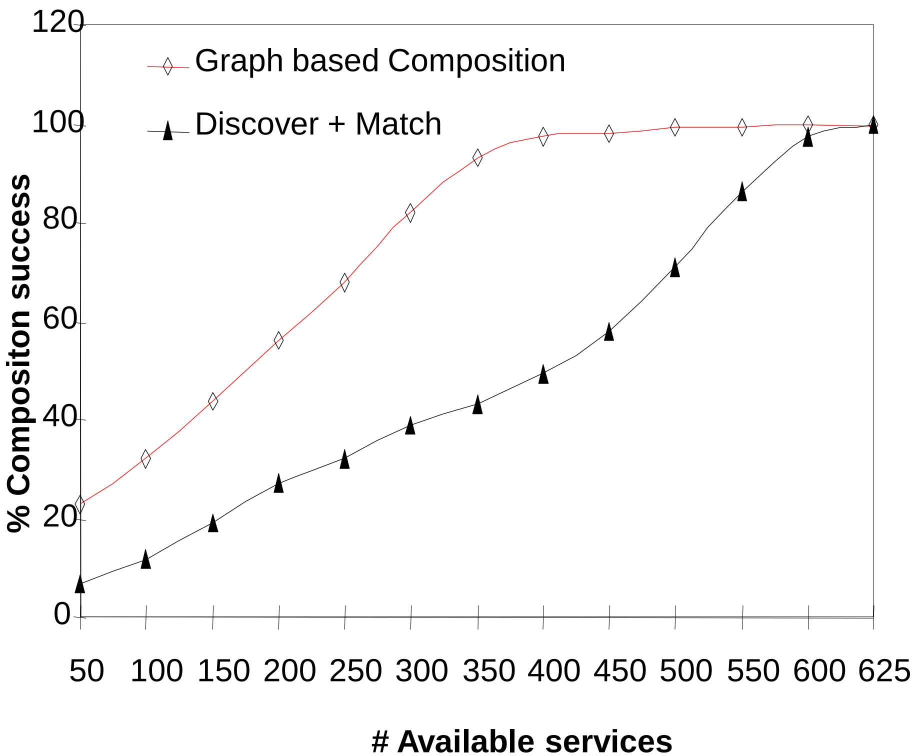
Hierarchical service composition

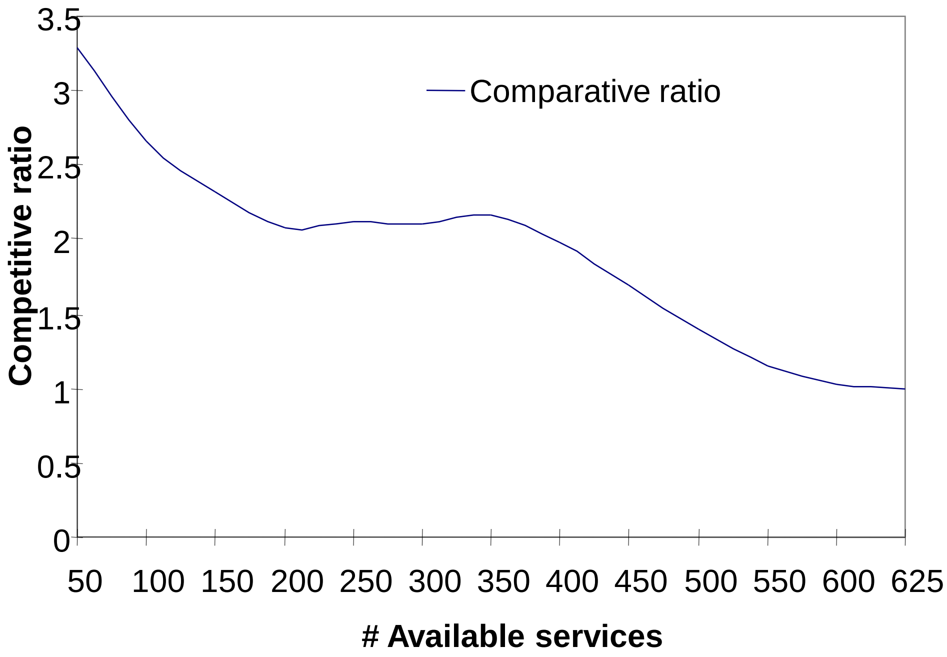




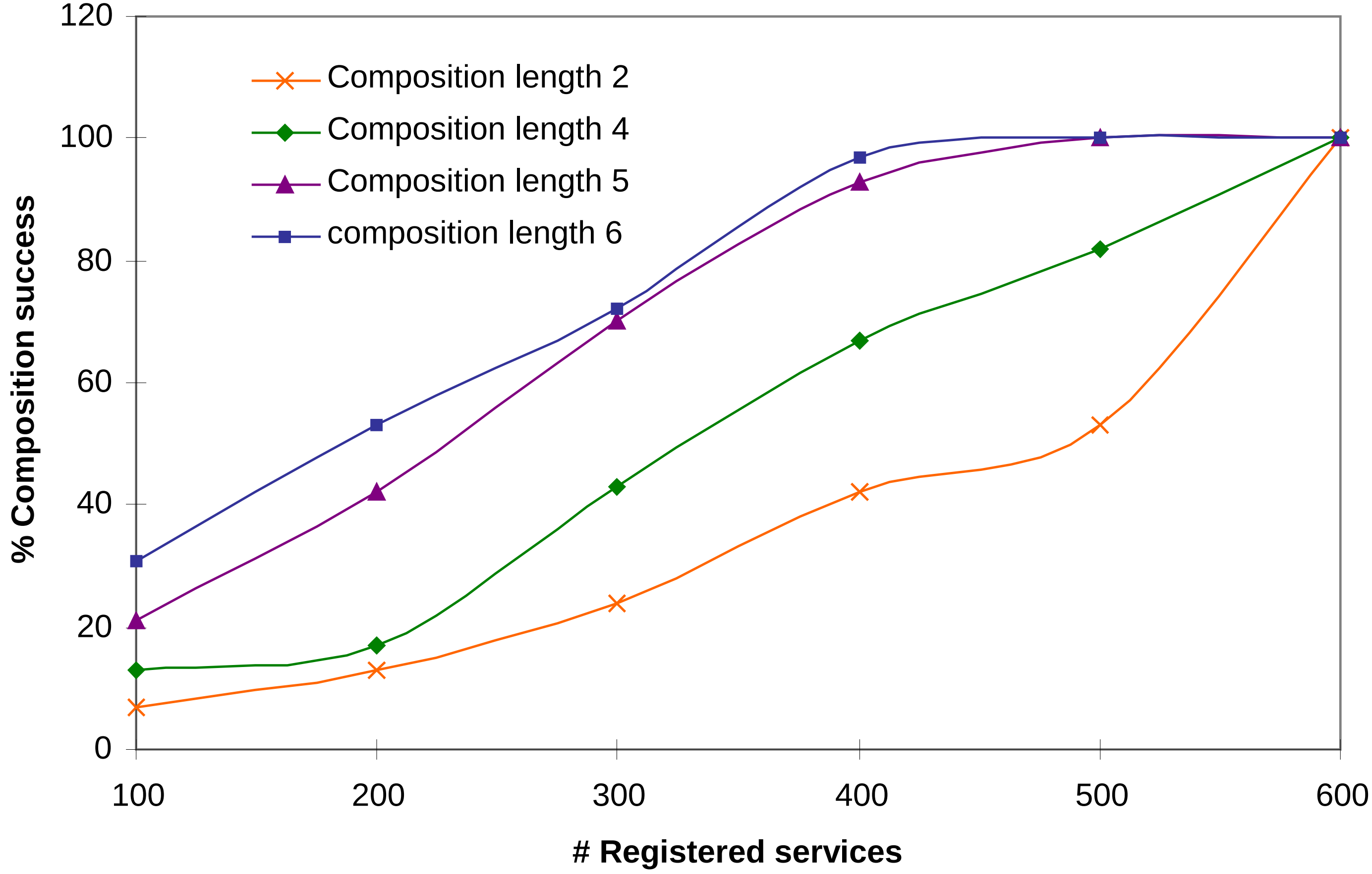
Request at D3

Comparison with D + M approach



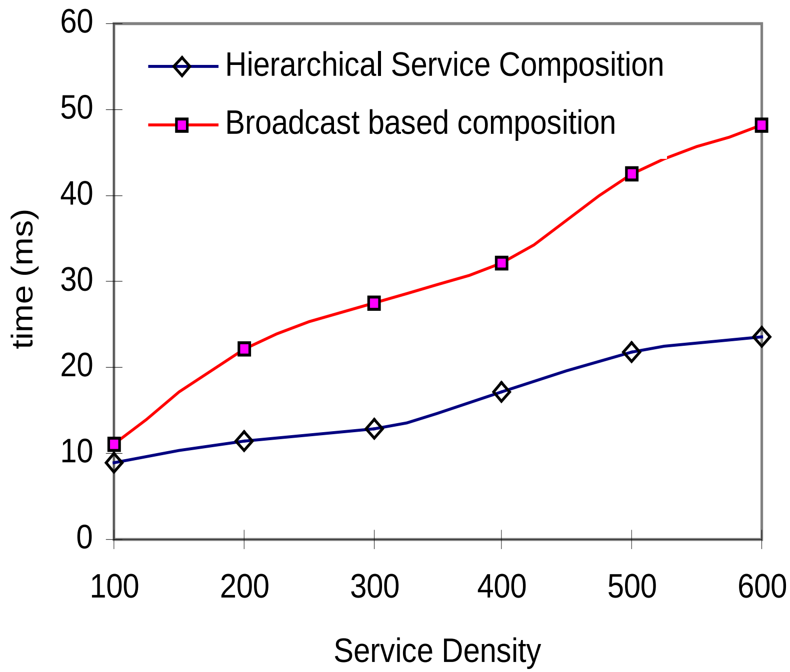


Service composition success rate Based on the composition length



User Mobility

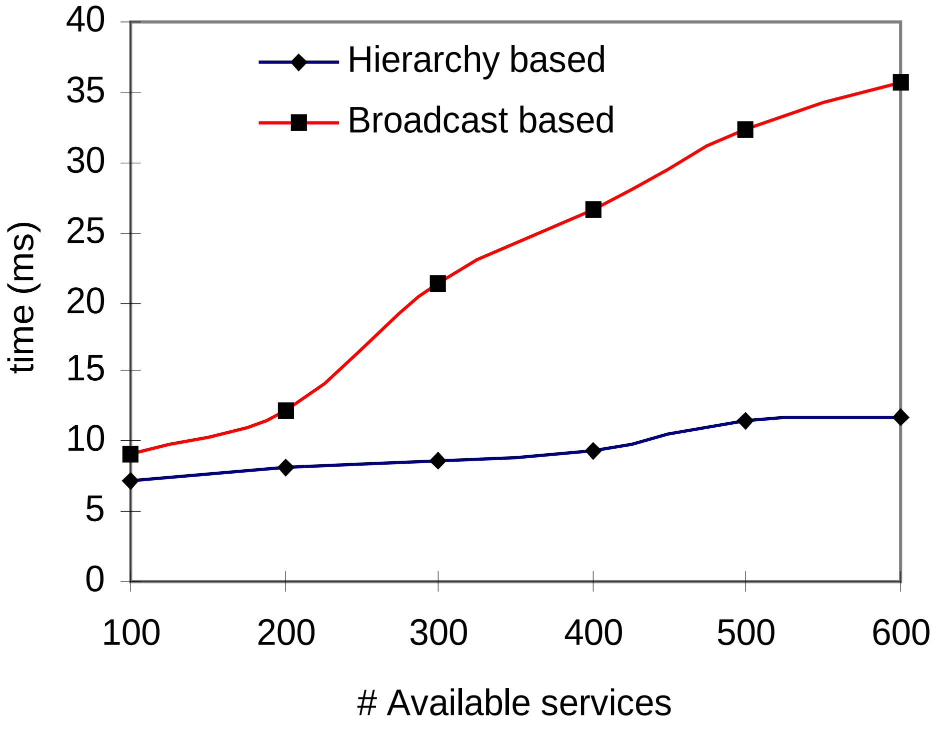
- User mobility is inherent to pervasive computing environments
- When a user moves in the middle of a service session, continued service support needs to be ensured
  - **By reconstructing the part of the service that was disrupted**
  - **Usually rendering services need to be reconfigured**



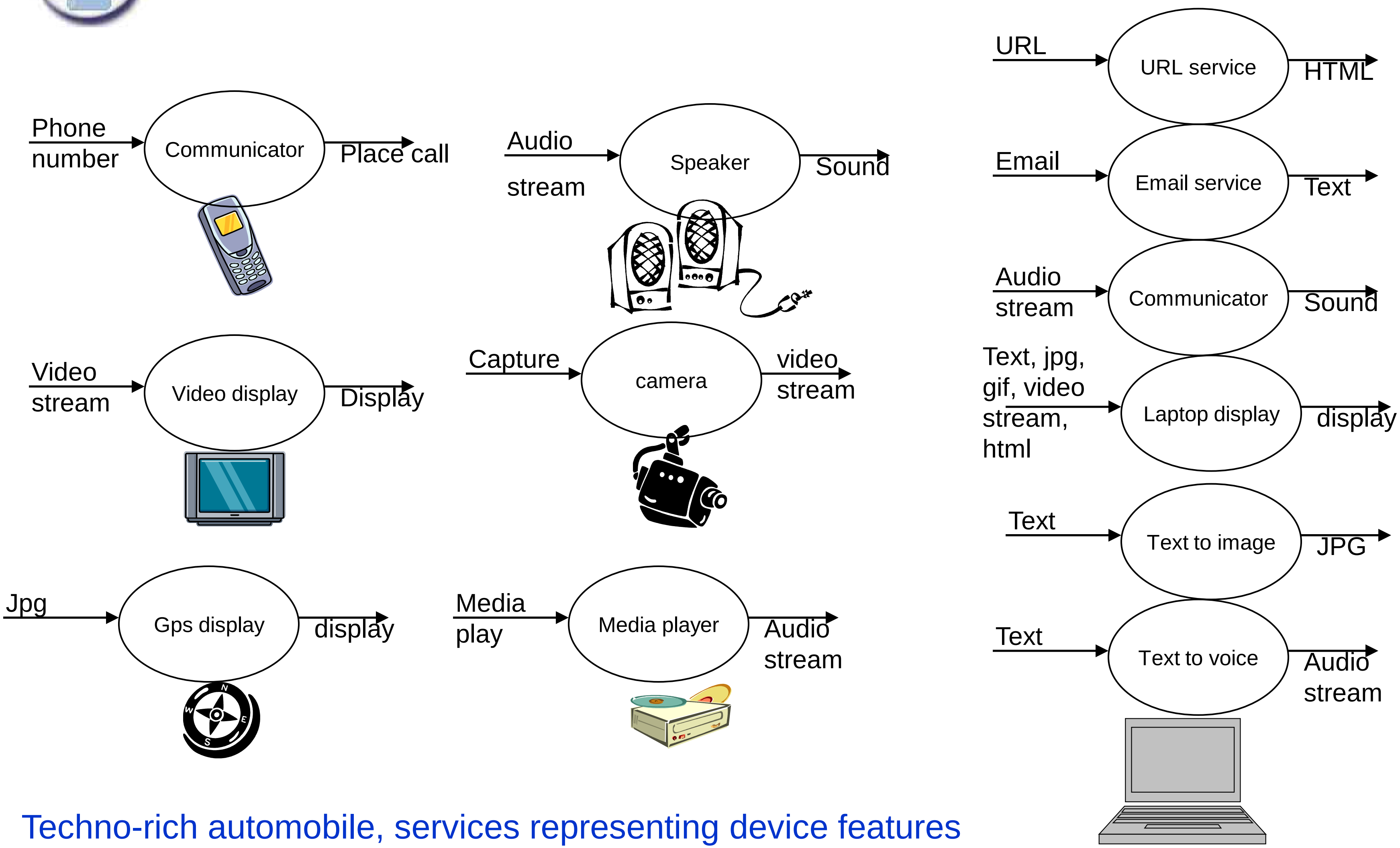
Resource mobility

- Mobile resources
- Resource limitations
  - **Battery power, increased load, memory shortage**

- Parts of the composition which are no longer valid need to be recomputed
  - The disconnected node could be a higher level node
  - More taxing as compared to user mobility



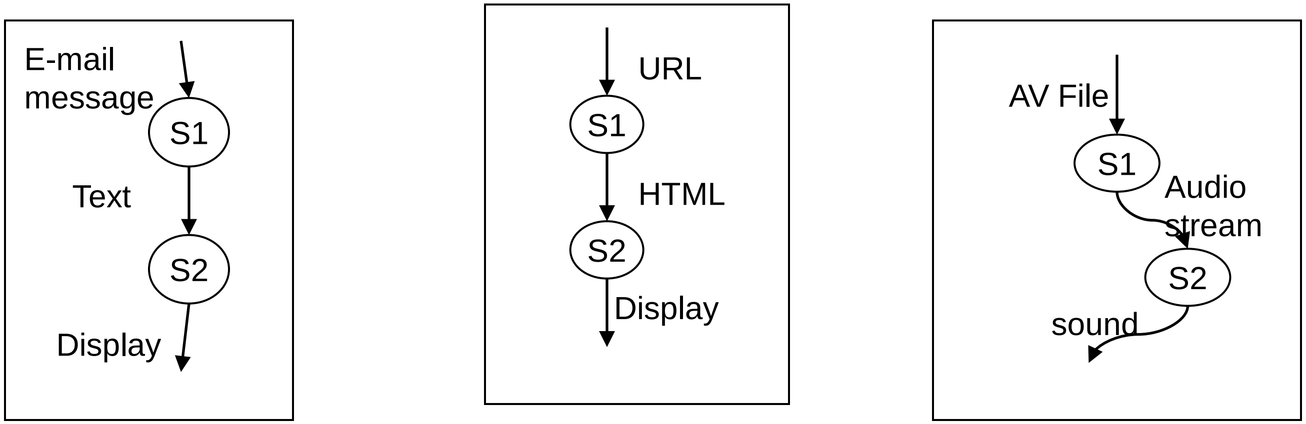
SOA: An Example



Techno-rich automobile, services representing device features

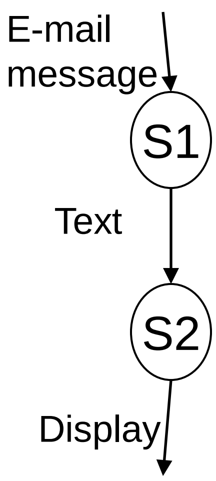
SOAs in action

- Tasks can be executed using available services
- Tasks represented as directed, attributed graphs
  - Nodes represent required services
  - Edges represent transformations among services
- Task graph acts as a *template* for locating and utilizing services

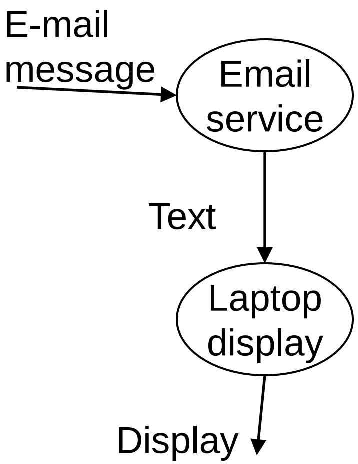


Example tasks

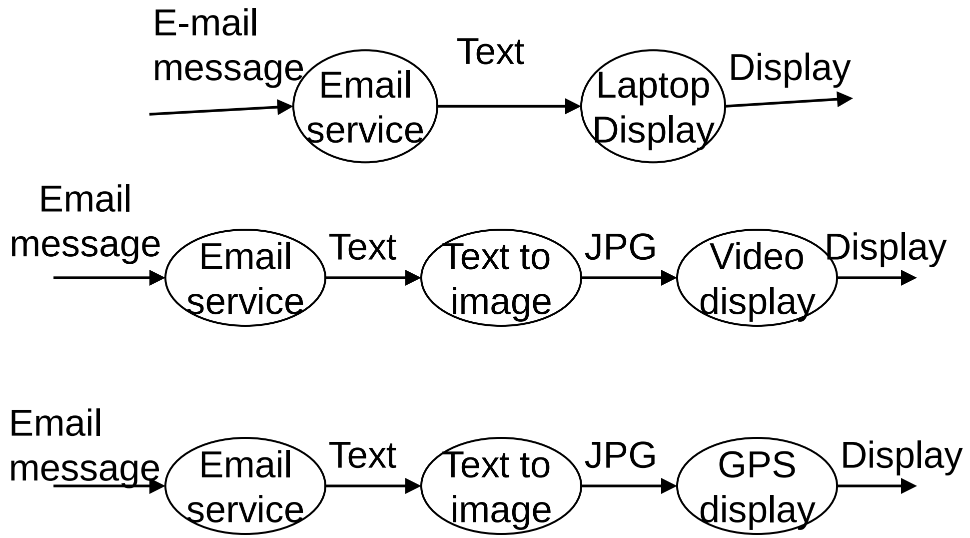
Comparing delivery mechanisms



Task representation

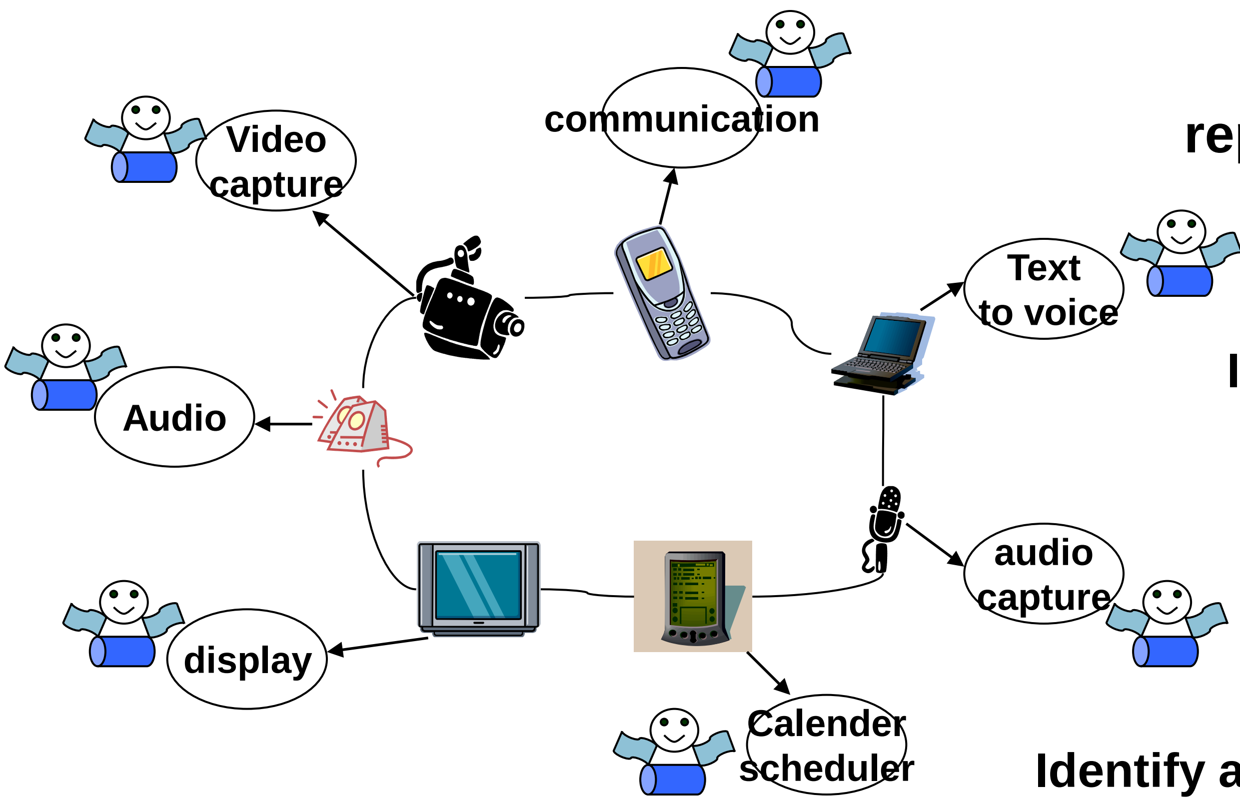


Composing with D+M



Composing with SeSCo

Modeling devices within an automobile



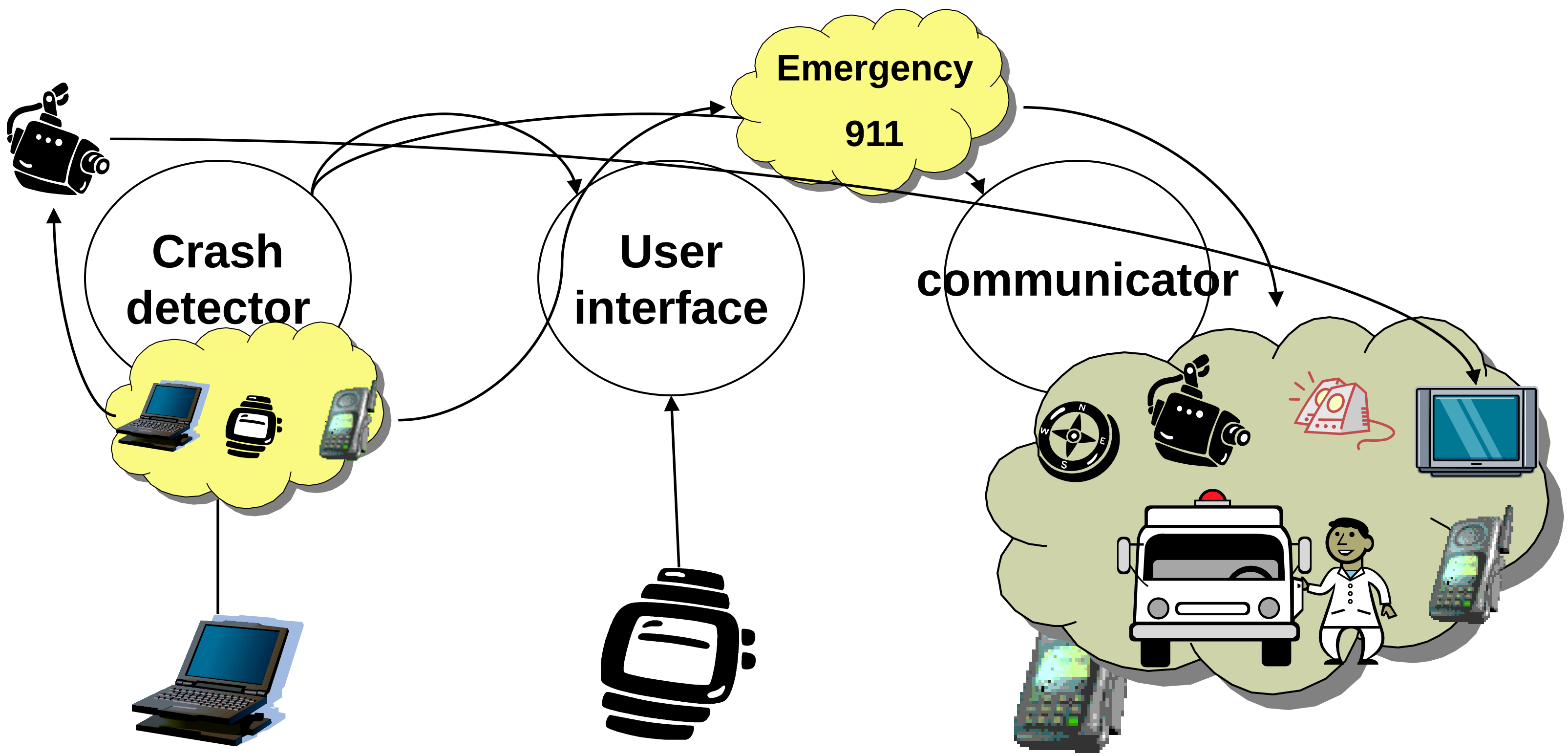
Create services representing identified features

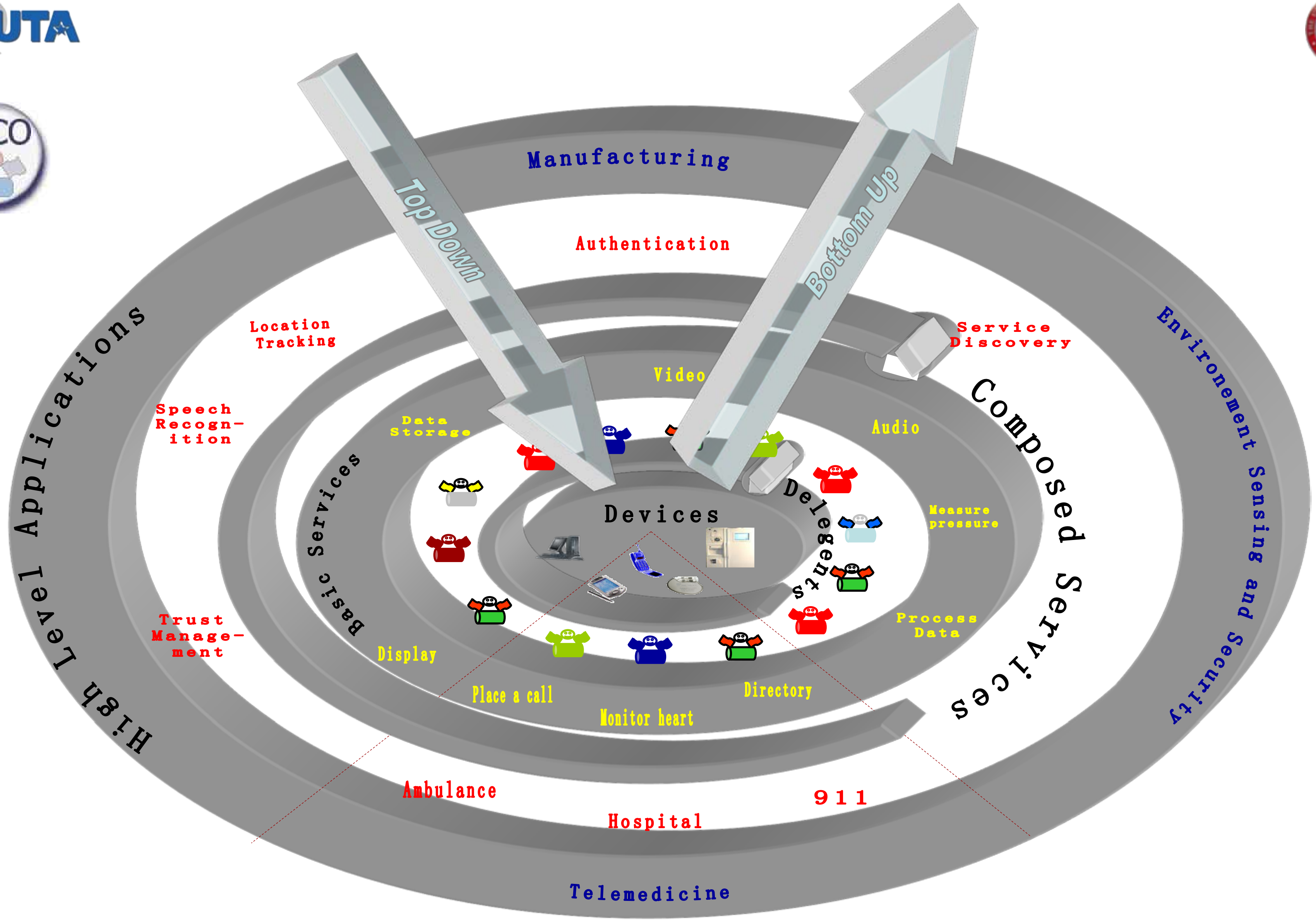
Identify features

Create a network among devices

Identify available devices

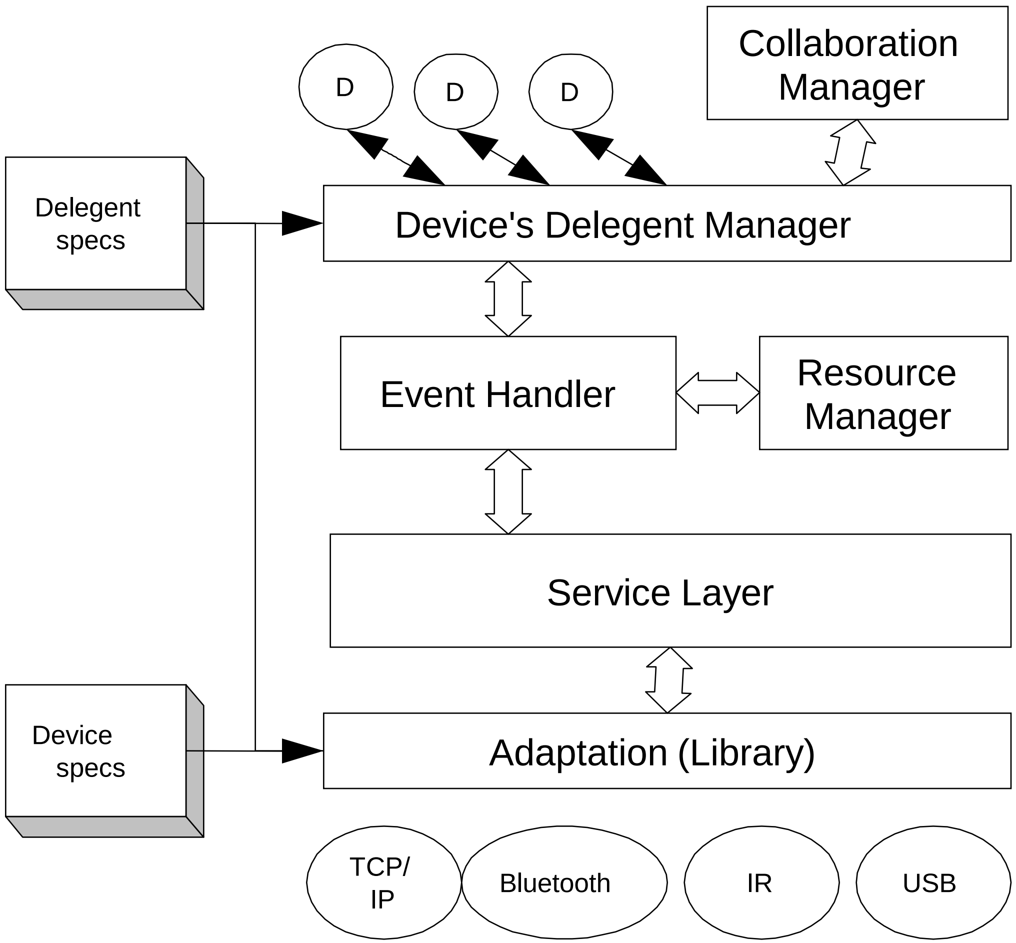
Prototype details





Available and accessible services

PICO Middleware



Organization

- Motivation
- Pervasive Computing
- PICO project at CSE@UTA
- Services in pervasive environments
  - Modeling services
  - Service Composition
  - Hierarchical Service Composition
- SeSCo – Seamless Service Composition
- Conclusions
- Ongoing and Future work – Possible Collaborations

Conclusions

- SOAs to build pervasive computing systems
  - Resources exported as services
  - Service composition mechanism to deliver task support
- SeSCo capable of providing advanced support
  - Capability to dynamically *weave* composite services from basic ones
  - Maintains locality of service, quality of composition
  - Capable of handling user and resource mobility
- Hierarchical service overlay
  - Formed based on resource states
  - Enables resource poor devices to exploit presence of powerful devices
- Dynamic mechanism to maintain overlay and composite services
  - Reflects current resource status
  - Can maintain composite service sessions

Publications

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- H. Ko, G. West, S. Venkatesh, and **M. Kumar**, *Online Temporal Fusion in Multisensor Systems using Dynamic Time Warping*, Information Fusion Journal, In Press.
- M. Kim, **M. Kumar**, and B. Shirazi, *Service Discovery using Volunteer Nodes in Heterogeneous Pervasive Computing Environments*, Elsevier's Pervasive and Mobile Computing, In Press.
- H. Alex, **M. Kumar**, and B. Shirazi, MidFusion: An Adaptive Middleware for Information Fusion in Sensor Network Applications, Information Fusion Journal, In Press. M. Kumar et al., Pervasive *Information Communities Organization PICO: A Middleware Framework for Pervasive Computing*, IEEE Pervasive Computing, July-September 2003, pp. 72-79.
- S. Kalasapur, M. Kumar, B. Shirazi, *"Evaluating Service Oriented Architectures in Pervasive Computing,"* In proceedings of the fourth international conference on Pervasive Computing and Communications, *PerCom 2006*, Pisa, Italy.
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- S. Kalasapur, M. Kumar, B. Shirazi, *"Seamless Service Composition (SeSCo) in Pervasive Environments,"* In the proceedings of the first international workshop on Multimedia Service Composition, *MSC 2005*, November 2005, Singapore.
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