Contory: A Middleware for the Provisioning of Context Information on Smart Phones

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What's Context-awareness Today?

It's Friday 6pm, Jani is driving downtown to have dinner with his wife. Today Lappi Restaurant has a special on Grilled Fillet of Elk…

Do you want me to book a table outside for two persons? There are several free parking spots on Albertinkatu 19-25.

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Let's Implement It Now!

- We need sensors
  - for location
  - for weather forecast (temperature, wind, humidity)
  - for free parking spots
- Where do we put the sensors and who processes the sensor data?
  - Your mobile phone
    - Load could be too high and sensors too many!
  - There is a city infrastructure
    - What's the coverage? What's the cost? What's the granularity of the information provided?

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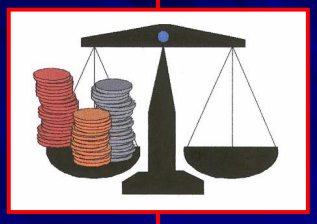

- Context-awareness is resource-expensive
  - Complex computations
  - A variety of sensors
- Highly dynamic environments
  - Proactive interactions

- Mobile devices are resource-poor
- Infrastructures cost and cannot be deployed everywhere

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Keys to Success in Context Provisioning on Mobile Devices

- Sharing resources
  - Sensors, services, connectivity, computation
- Flexibility
  - Exploit resource-rich environments, survive in resource-poor environments
- Trading off quality and cost
  - Performance is important, power is essential!

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- Integrate multiple context provisioning strategies
- Exploit spontaneous networking of sensors, phones, devices
- Allow monitoring local and remote contexts
- Provide programmers with the abstraction of a context database

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Outline

- Motivation
- Design Principles
- Software Architecture
- Implementation and Evaluation
- Conclusions and Future Work

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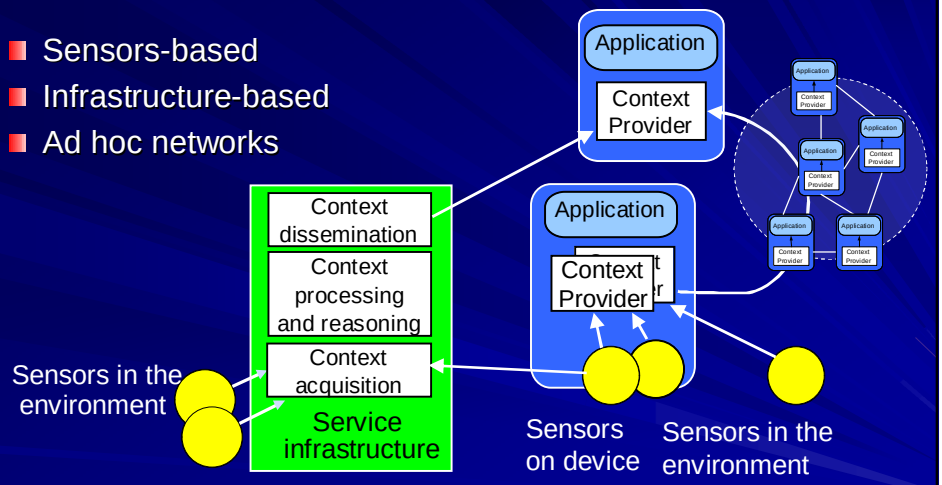
Reliable Multi-Strategy Context Provisioning

- Sensors-based
- Infrastructure-based
- Ad hoc networks



- Hard to rely only on one provisioning mechanism
- Contory integrates all 3 strategies

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Context Database Abstraction

```
SELECT <context type>
FROM <source>
WHERE <predicate clause>
FRESHNESS <time>
DURATION <duration>
EVERY <time> | EVENT <predicate clause>
```

Example:

```
SELECT temperature
FROM adHocNetwork(first3,3)
WHERE accuracy = 0.2
FRESHNESS 30 sec
DURATION 1 hour
EVENT AVG(temperature)>25
```

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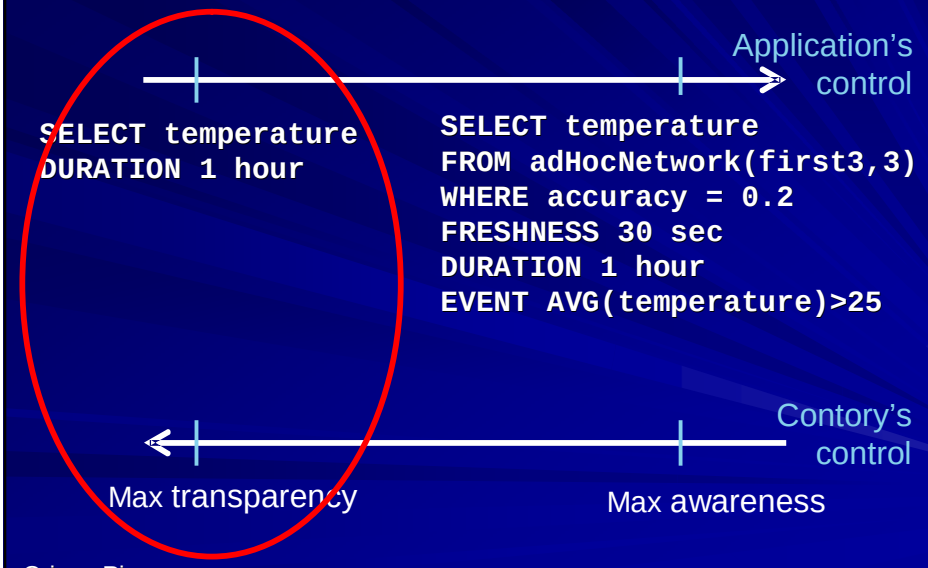
Transparency vs. Awareness



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Resource-driven Execution

- Monitor available resources
  - power, memory, running applications, etc.
- Trade off quality and resource consumption
- Reduce the global utilization of resources
- Prioritize tasks
  - Context-awareness is a background activity on phones

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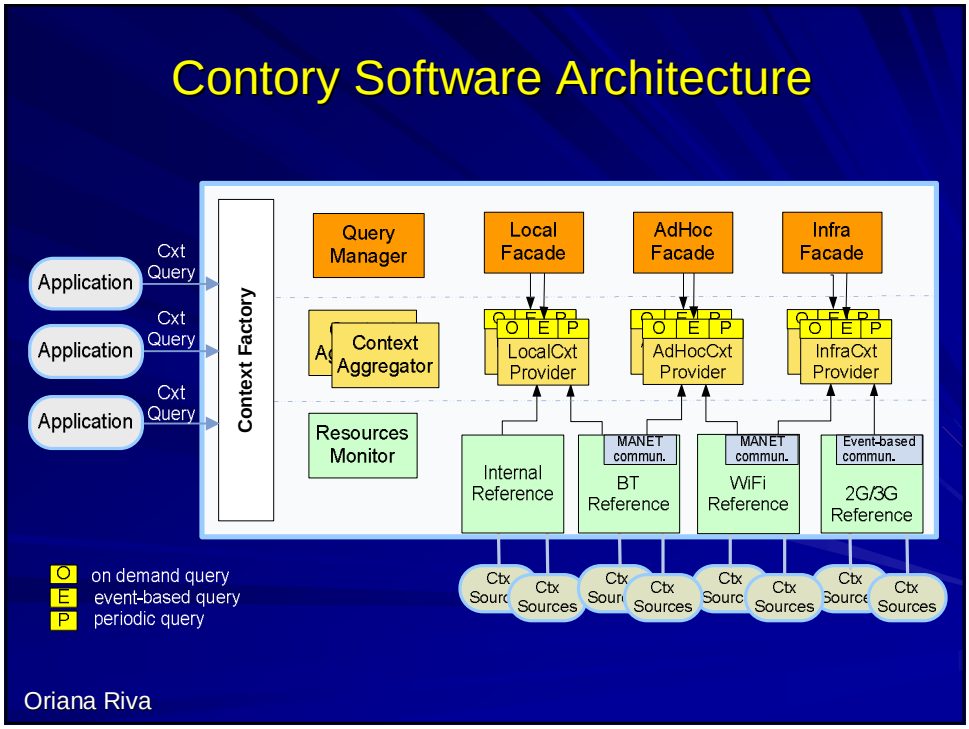
Contory Software Architecture
Application
Application
Application
Cxt Query
Cxt Query
Cxt Query
Context Factory
Query Manager
Context Aggregator
Resources Monitor
Local Facade
AdHoc Facade
Infra Facade
O E P
LocalCxt Provider
AdHocCxt Provider
InfraCxt Provider
Internal Reference
MANET commun.
BT Reference
MANET commun.
WiFi Reference
Event-based commun.
2G/3G Reference
Ctx Sources
O on demand query
E event-based query
P periodic query
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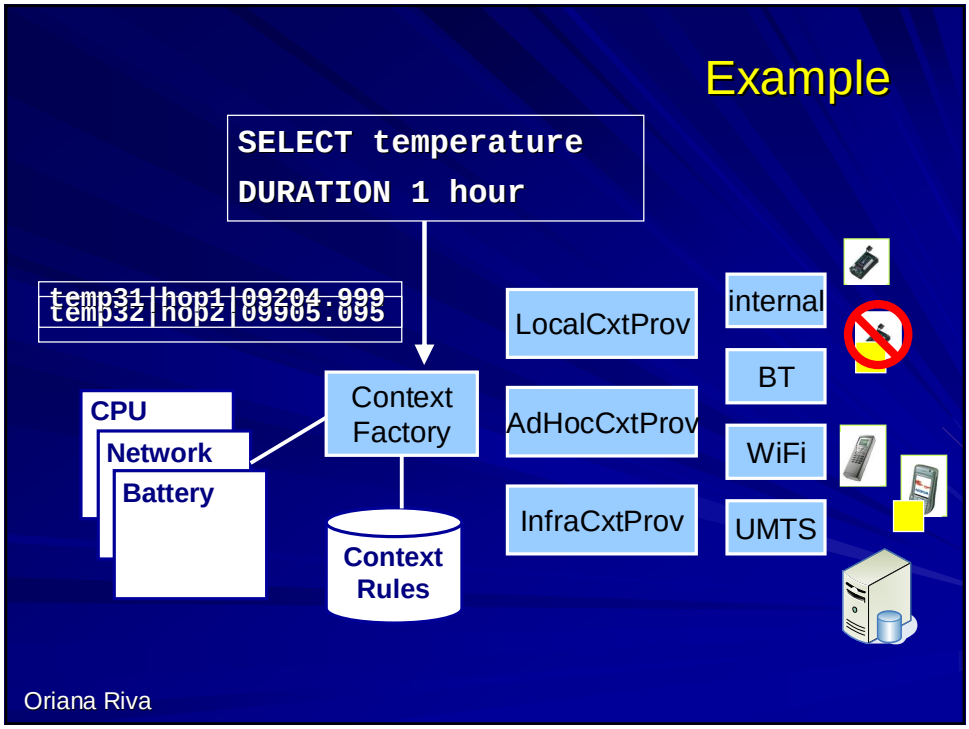
Example
SELECT temperature
DURATION 1 hour
temp31|hop1|09204.999
temp32|hop2|09905.095
CPU
Network
Battery
Context Factory
Context Rules
LocalCxtProv
AdHocCxtProv
InfraCxtProv
internal
BT
WiFi
UMTS
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Distributed Context Provisioning

- One-hop: Bluetooth-based
- Multi-hop: WiFi-based
- Three phases:
  1. Initialize the Reference on the node
  2. Publish context items
  3. Execute the query
- With Bluetooth: creation of a service record in the Service Discovery Database

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Distributed Context Provisioning – cond't

- With WiFi: *Smart Messages* (SM) platform
- Similar to a mobile agent, an SM-FINDER discovers context items in the ad hoc network
- Execute on nodes of interest named by properties
- Migrate between nodes of interest
  - Self-route at every node in the path during migrations
  - Use geographical routing and content-based routing

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Query Aggregation

- Query merging
  - `Q3 = Merge(q1,q2)`
- Post-extraction
  - `R(q3)→ R(q1),R(q2)`
- `if(distance(q1,q2)<threshold)then Merge`
- Merge through clause-specific merging rules
- Currently done only at the application node
- Ongoing work: in-network query aggregation

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Current Prototypes

- Implemented in Java
  - Java 2 Micro-Edition (J2ME) with CLDC 1.1 and MIDP 2.0
  - J2ME with CDC
- Development using Nokia Series 60 phones and Nokia Series 80 phones

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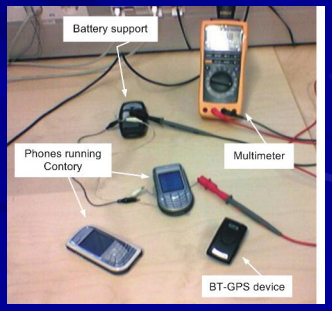
Experimental Evaluation

- Goals:
  - Demonstrate the feasibility of our approach
  - Quantify its cost in terms of energy consumption
- Testbed
  - Nokia 6630, Nokia 7610, 3 Nokia 9500 phones
  - BT-GPS device
  - Fluke 189 Multimeter



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Latency Experiments

Publish Context Item

Strategy	Avg latency (msec)
Ad hoc network – BT	140.4
Ad hoc network - WiFi	0.1
Ext-infrastructure - UTMS	772.7

Get Context Item

Strategy		Avg latency (msec)
Ad hoc network – BT		31.8
Ad hoc network - WiFi	1 hop	761.3
	2 hops	1422.5
Ext-infrastructure - UTMS		1473.0

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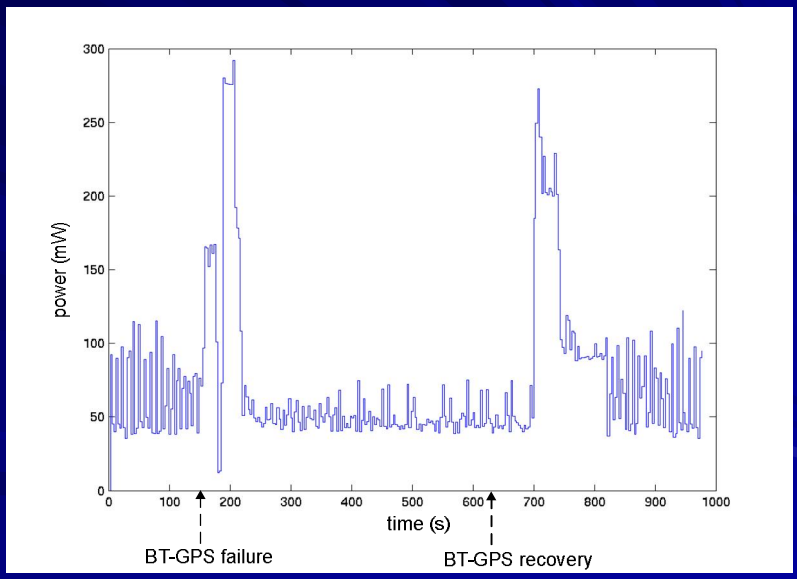
Power Consumption: BT-GPS Failure



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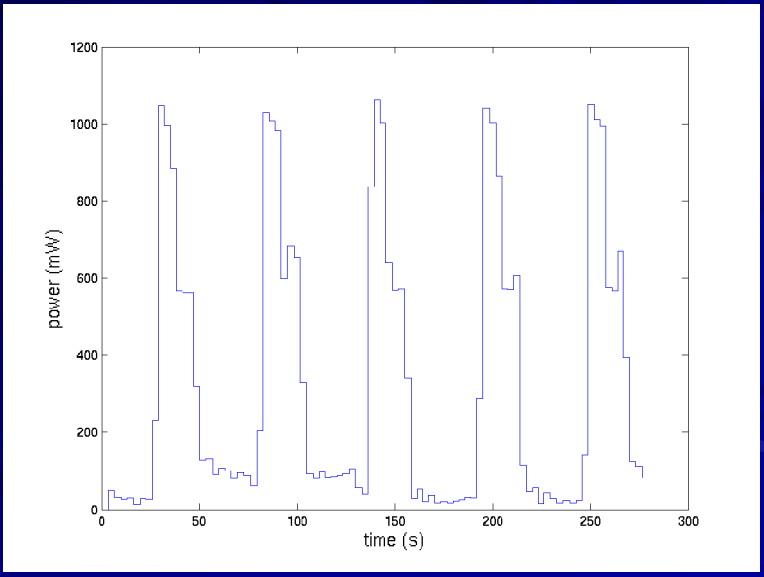
Power Consumption: extInfra Provisioning



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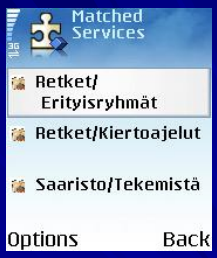
Prototype Applications

Context-based service provisioning



Weather Watcher

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Conclusions

- Mobile phones can be successfully programmed to support context-awareness
- Spontaneous networking offers interesting avenues for new context services
- But there is a big problem to solve: POWER!

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Future Work

- Distributed context provisioning
  - In-network query and data aggregation
- Learning resource utilization
  - Hard to specify resource usage and policy controls
  - Lots of resources
  - Platform-dependent

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Thank you!

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