Context-Aware Cognitive Radio

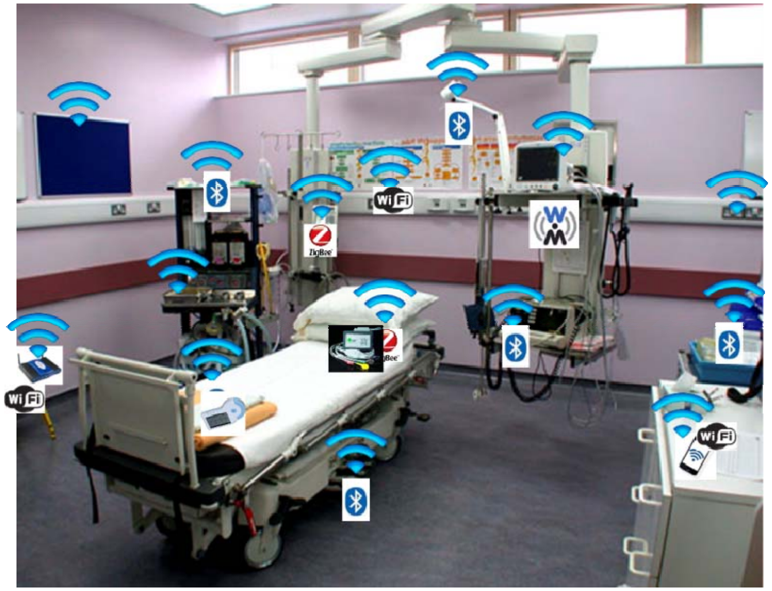
James Neel[1], Pete Cook[1,2]. Ihsan Akbar[3], Daniel Devasirvatham[4], Charles Sheehe[5], Neal Mellen[6], Bob Schutz[7]

1. **Cognitive Radio Technologies**
2. Peter G. Cook Consultancy
3. Harris Corporation
4. Wi-Plan Wireless Consulting
5. NASA
6. Wireless Spectrum Management, LLC
7. Artisan Wireless Solutions

What is context?

What is Context?

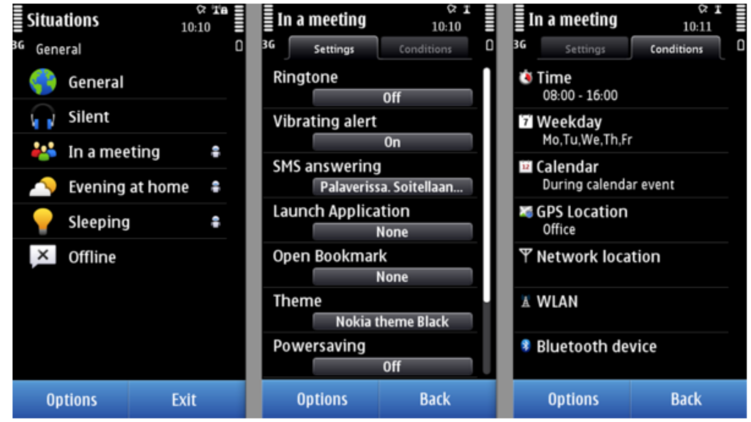
- **Context**:
  - the parts of [communications] not directly communicated that influence its meaning or effect (Modified from dictionary.com)
  - any information that can be used to characterize the situation of an entity (Dey)
- **Situations**
  - external semantic interpretations of context
  - objects having properties and standing in relations to one another
- **Episodes**
  - Situations in time



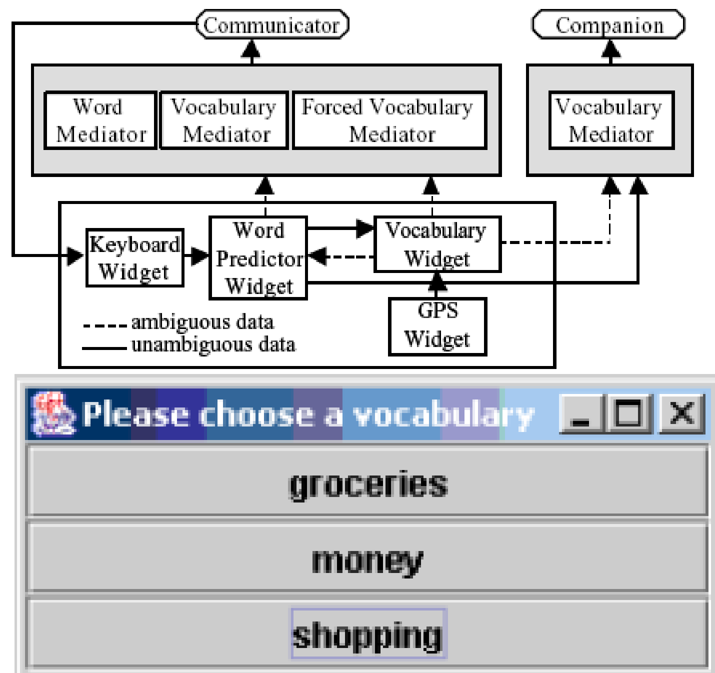
Contextually Aware Applications and Tools

- Qualcomm's Gimbal [Gimbal] uses location, time of day, web history, apps and app usage to infer information about the user and provides a series of libraries (e.g., geo-fencing) to build and deploy context-aware applications for iOS and Android platforms.
- Really Simple Context Middleware [RSCM] is open source software for developing context-aware applications for Android platforms. It provides libraries for sensing battery levels and location and for reasoning about user activity (e.g., inferring if the user is walking).

Situations from Nokia



http://www.readwriteweb.com/archives/nokias_new_situations_app_makes_phones_self-aware.php

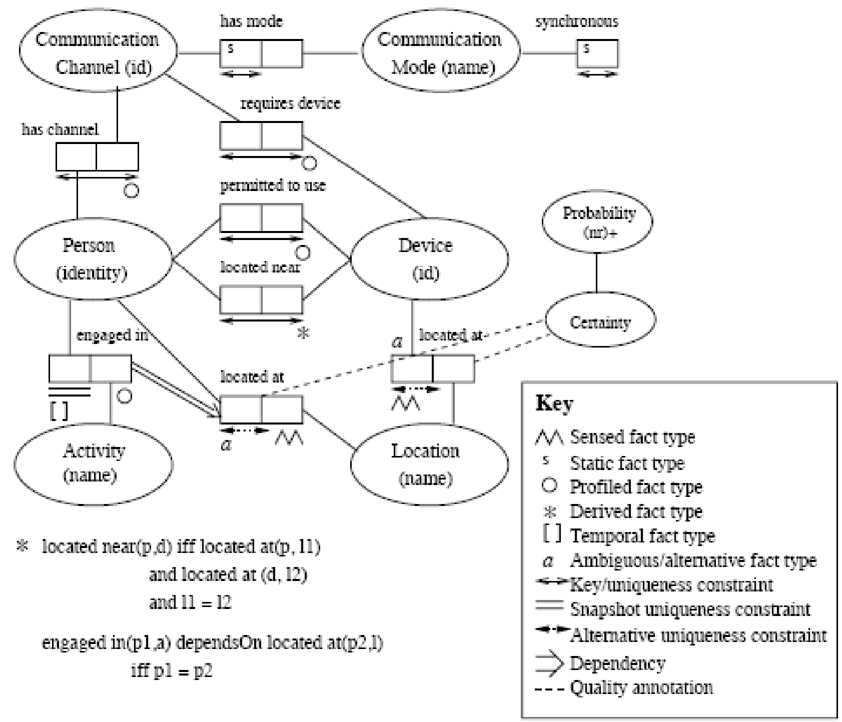


A. Dey, J. Mankoff, "Designing Mediation for Context-Aware Applications," ACM Transactions 2005

Selected Surveyed Context Models

- Object role-models (ORM)
  - Focuses on “fact-based modeling”
- Context Modeling Language (CML) adds to ORM
  - Source of info, e.g., static, sensed, derived, and user-supplied (“profiled”) information;
  - imperfect information using quality metadata
  - concept of “alternatives” for conflicting assertions (such as conflicting location reports from multiple sensors)
  - capturing dependencies between context fact types; and
  - capturing histories for certain fact types and constraints on those histories.
- Context Information Model adds
  - Geometric coordinates (e.g., GPS)
  - Symbolic coordinates (e.g., room number)
- Ontology Based
  - Equator Project
  - SOUPA, CONON
- CRWG converged on **<u>Context Toolkit</u>** as context model we liked best
  - Code, Examples, Numerous publications

A CML Model



Context Toolkit

- Work of Anind Dey and Gregory Abowd
  - Originally Georgia Tech ~1999
  - Since elsewhere
- Not focused on wireless applications; we're repurposing

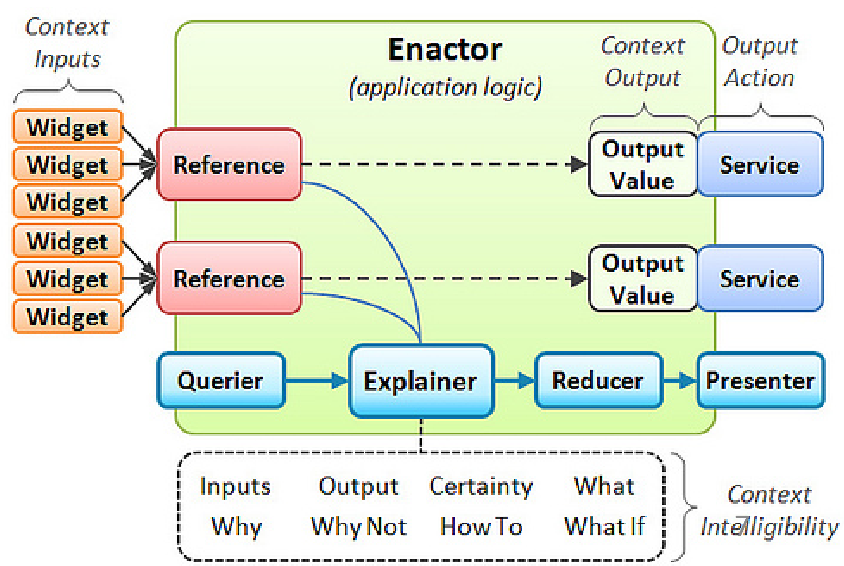
- Reference pages
  - http://www.contexttoolkit.org/
  - http://www.cc.gatech.edu/fce/contexttoolkit/
  - http://www.cs.cmu.edu/~anind/context.html
- Available for download:
  - http://contexttoolkit.googlecode.com/

- the In Out Board described above
- an information display that shows a user standing in front of it, a URL related to the research group that they are in
- Dummbo, an augmented whiteboard, described above. More information here
- a context-aware mailing list that only sends an incoming email to those people who are currently in the building
- a Conference Assistant that aids users when attending a conference. More information here
- CybreMinder, a context-aware system that supports the creation, delivery, and handling of reminders. More information here
- a series of demonstration applications for the Aware Home, including the Smart Intercom
- Augmented Wheelchair, a context-aware communication system that uses context to improve word prediction for mobile and speech-impaired users. More information here and here

Major Components in Context Toolkit (ignoring the glue components)

- **<u>Widget</u>** – all purpose class that everything inherits from
  - Can store information, or context
- **<u>Sensors</u>** – widget that turns real world data into contextual information
  - one or more attributes accessible to other widgets
  - E.g., light level
- **<u>Generators</u>** – update the sources of information used by the sensors
  - Models real world processes when no real world component exists
    - Read from a file
  - Implemented as an enactor without an input
- **<u>Services</u>** – the actuator of the model; physically does "stuff"
  - E.g., turn on a light…
- **<u>Enactors</u>** – perform reasoning on inputs to create outputs

1. Model states with Widgets
2. Model reasoning with Enactors
3. Model behaviors with Services
4. Combine into a Context Model



Why Context Aware Cognitive Radio?

Big RF

Efficient & Effective Communications

Better Cognitive Radio Decisions

Big RF Will Be a Problem

- Big Data (loosely defined)
  - a collection of emerging techniques and processes for rapidly acquiring, classifying, and synthesizing meaning from Terabytes or Petabytes of data
  - the data itself.
- Big RF
  - Big Data Problems in the RF Domain

Volume the amount of data, e.g., Intel's factories generate 5 Terabytes / hour [2] and 12 Terabytes of Tweets are created daily [3]

Velocity the rate of data acquisition, e.g., high frequency trading

Variety the range of data types and sources, e.g., text, HTML, pictures, sound, etc.

Veracity the accuracy of the data, e.g., weather forecasts are only valid for a certain period of time but also include an element of confidence

Velocity A single spectrum logger, such as D-TA's RFVision 2 logs data at the rate of19.2 Gbps [5]. To maintain a nationwide network of such sensors mounted at each cell tower in the US (260,000 towers) [6] would generate approximately 5 Petabits of data per second.

Volume To analyze trends over a single year without loss of data, this would then require 15.7 Zetabits of storage

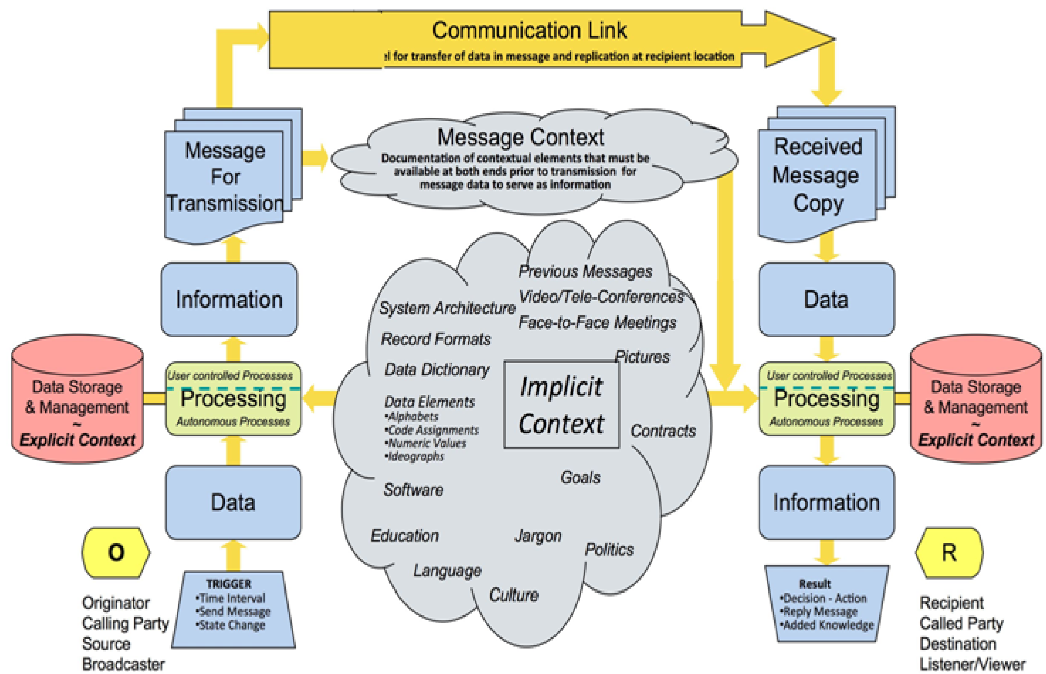
Variety More realistically, spectrum measurements would come from a variety of sources, such as cell phones, base stations, and access points, which would have differing data formats and often duplicate observations of the same phenomena though with seemingly disparate measurements.

Veracity An important aspect of many communication links and networks is verification of the identity of the radio to determine the validity of the data being transmitted.

- CRWG believes that context will help make Big RF problems manageable.
  - Contextual reasoning
  - Preserving data context

Context in Communications

- Related insights from previous work (IPA v1,2):
  - Shared context between sender and receiver is critical to communications
  - Knowing you have a shared context can greatly reduce bandwidth requirements
  - Open problem of how a cognitive radio "knows" and shares its operational context



IPA Comm Cycle

Cognitive Radio Context

- Context is critical to assigning meaning to observations (data)
- Incorrect context assessment leads to bad decisions
- Information beyond the waveform stack

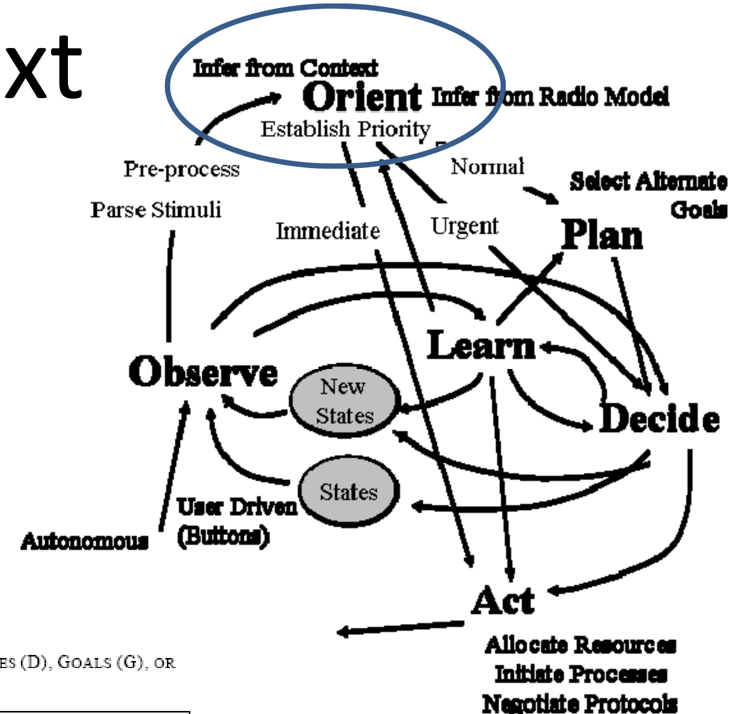
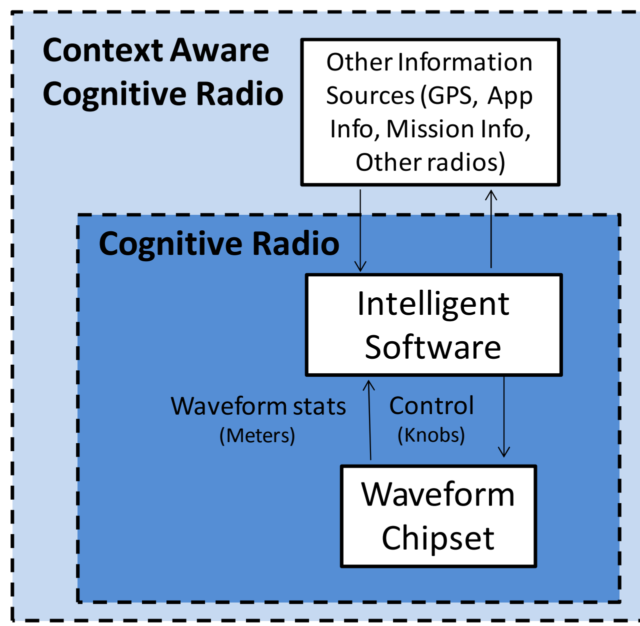


TABLE IV

EVEN WITH ALL OTHER PARAMETERS HELD CONSTANT, VARYING THE OBSERVATIONS (O), ACTIONS (A), DECISION PROCESSES (D), GOALS (G), OR CONTEXT (C) CAN LEAD TO RADICALLY DIFFERENT OUTCOMES

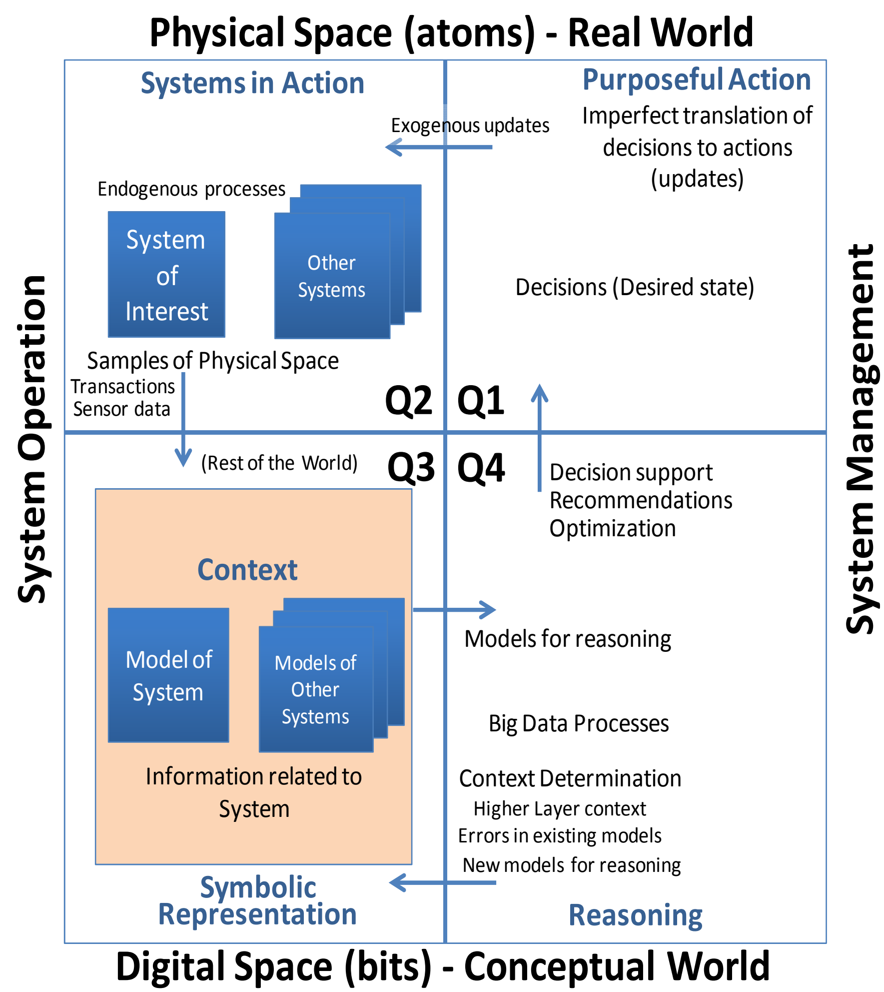
	Scenario 1			Scenario 2		
Observation	Parameters	O	*Interference at access point from other access points*	Parameters	O	*Interference seen by clients*
		A	Frequency (channel)		A	Frequency (channel)
		D	Lowest interference channel		D	Lowest interference channel
		G	Minimize interference		G	Minimize interference
		C	Tent city		C	Tent city
	Result	Converges to near-optimal frequency reuse pattern [48]		Result	Enters an infinite loop with probability 1 as network scales [51]	
Actions	Parameters	O	SINR at cluster head	Parameters	O	SINR at cluster head
		A	*Frequency*		A	*Power*
		D	Maximize goal		D	Maximize goal
		G	Maximize SINR		G	Maximize SINR
		C	Isolated cluster		C	Isolated cluster
	Result	Network tends to converge to low interference states		Result	Network tends to converge to self-jamming states	
Decisions	Parameters	O	Collisions	Parameters	O	Collisions
		A	Transmission times		A	Transmission times
		D	*Collaborate on times*		D	*Noncollaboratively choose times*
		G	Maximize collisions		G	Maximize collisions
		C	Isolated cluster		C	Isolated cluster
	Result	Rapid convergence to minimal interference state, adjustable to different user priorities		Result	Slow (if at all) convergence, throughput as low as ALOHA $(1/e)$	
Goals	Parameters	O	SINR at cluster head	Parameters	O	SINR at cluster head
		A	Power		A	Power
		D	Maximize goal		D	Maximize goal
		G	*Target SINR*		G	*Maximize SINR*
		C	Isolated cluster		C	Isolated cluster
	Result	If target SINR is feasible, converges to target SINR [78]		Result	Network tends to converge to self-jamming states	
Context	Parameters	O	SINR at cluster head	Parameters	O	SINR at cluster head
		A	Power		A	Power
		D	Punish (jam) radios deviating from target SINR		D	Punish (jam) radios deviating from target SINR
		G	Target SINR		G	Target SINR
		C	*Isolated cluster*		C	*Isolated cluster with a jammer*
	Result	Network overcomes defection problems for significant improvement in performance [41]		Result	Network self-jams as it "punishes" the jammer	



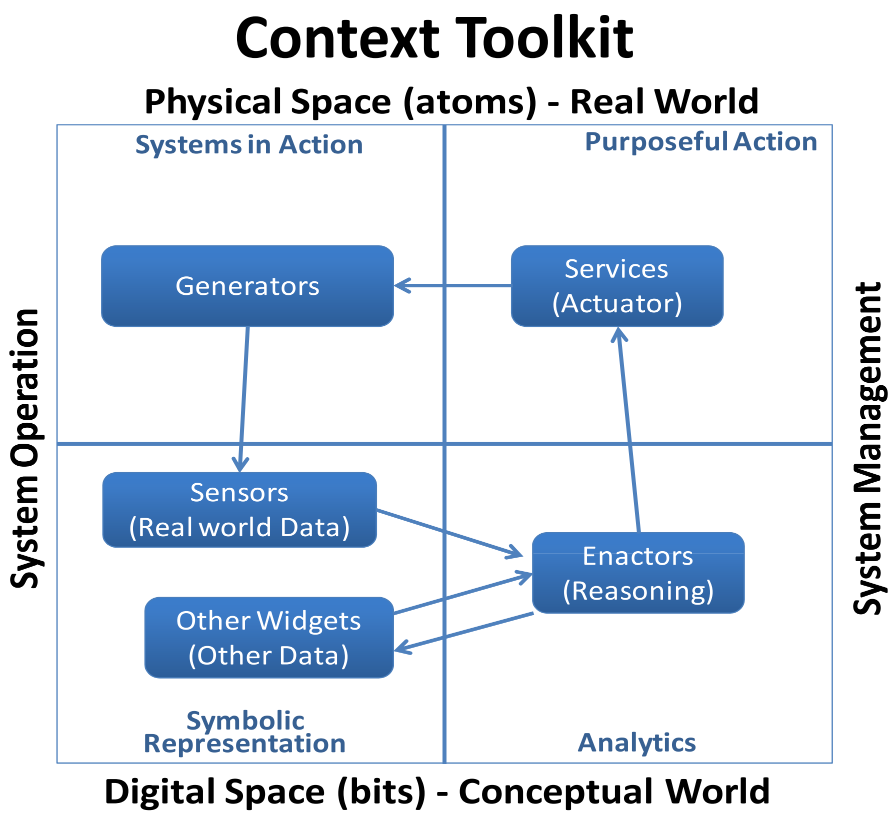
Modeling Context Reasoning Systems

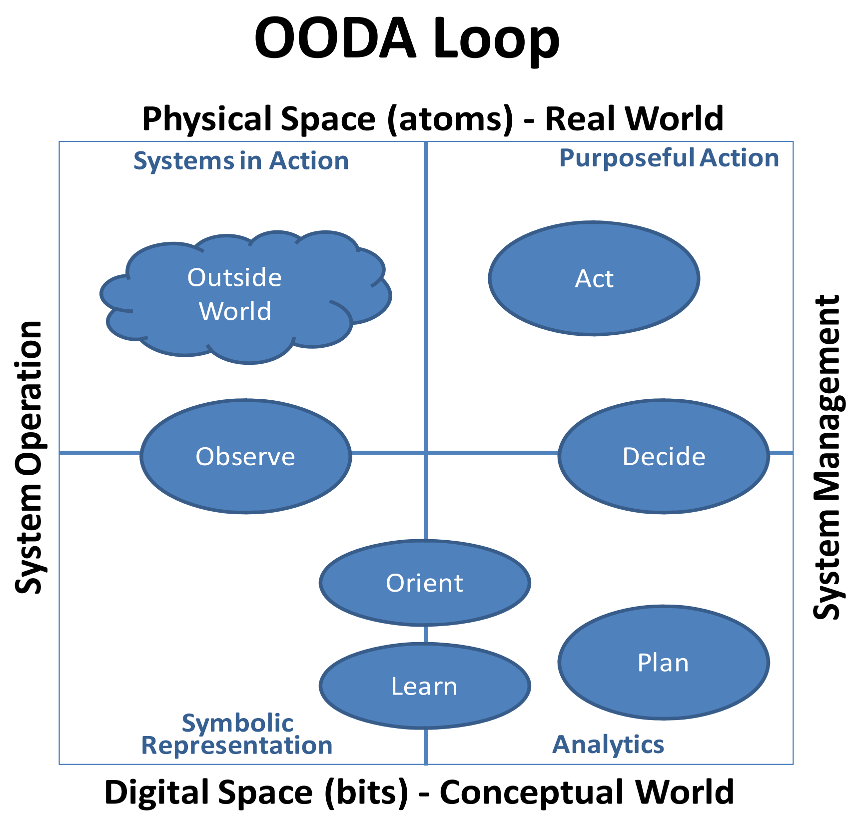
Wireless Information System Descriptive Model

- Model of how a contextually aware system reasons and interacts with the world
- Insights
  - Reason over models
  - Models updated by observations and reasoning
  - Model selection and parameters determine context
  - Processes are error-prone



Relationships with other Models

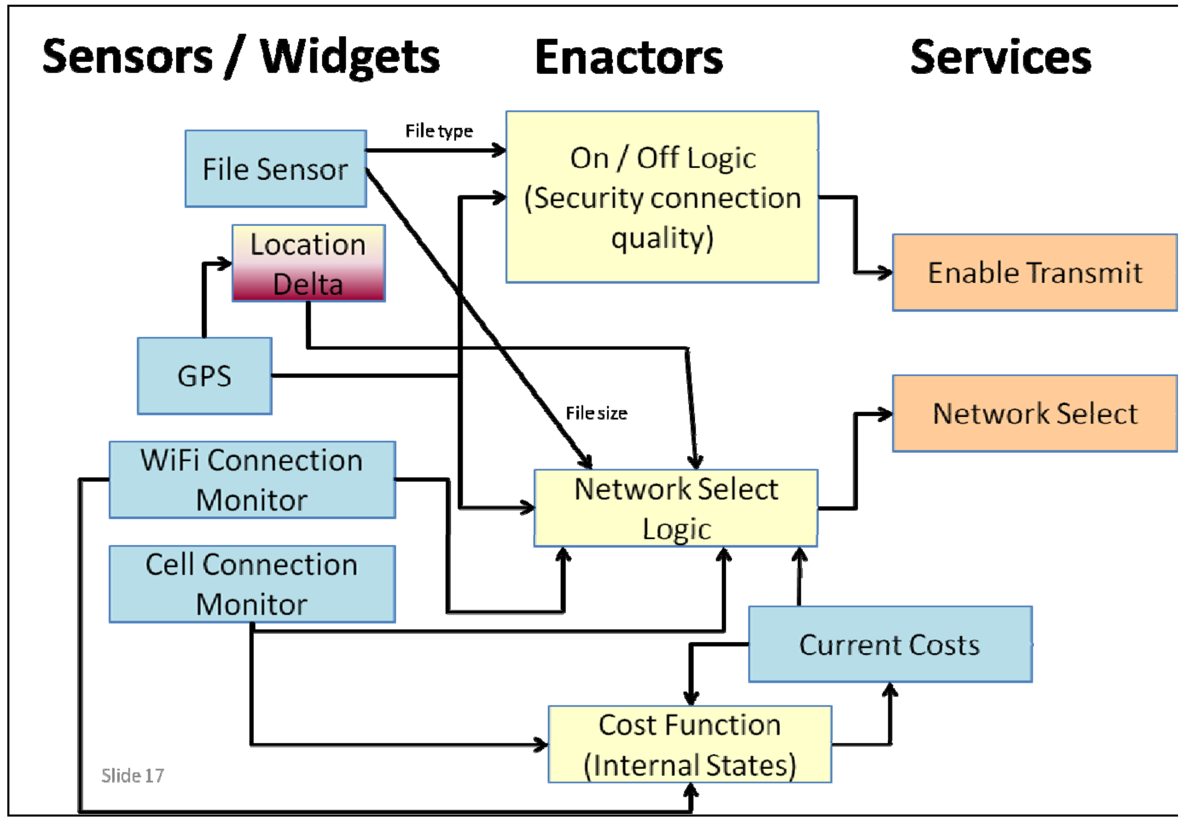




- Quadrants and basic flow of WISDM map well into existing models
- OODA loop mapping implies can represent human reasoning

Initial Application

- Continuing survey of context apps and use of context
- Coding (Java) a simple context aware cognitive radio application using the Context Toolkit
- Discussions and refinement of context for CR concepts

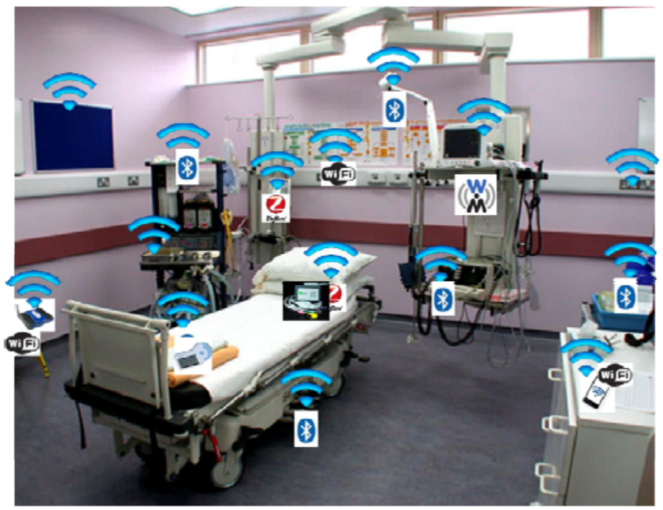


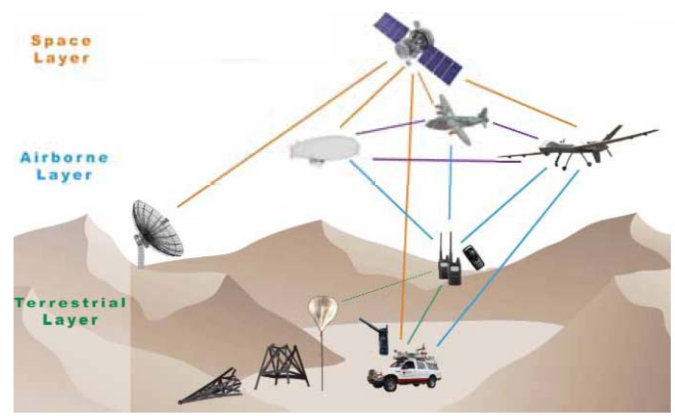
- Block diagram of simple context aware cognitive radio using context toolkit components

Insights and Conclusions

Contextual reasoning will benefit numerous applications

- Recognizing and reasoning over context will be increasingly important to emerging cognitive radio applications
- Significant benefits from joint optimization with app / user layer
  - Not as enthusiastic about joint optimization with layer 3/4 for commercial apps

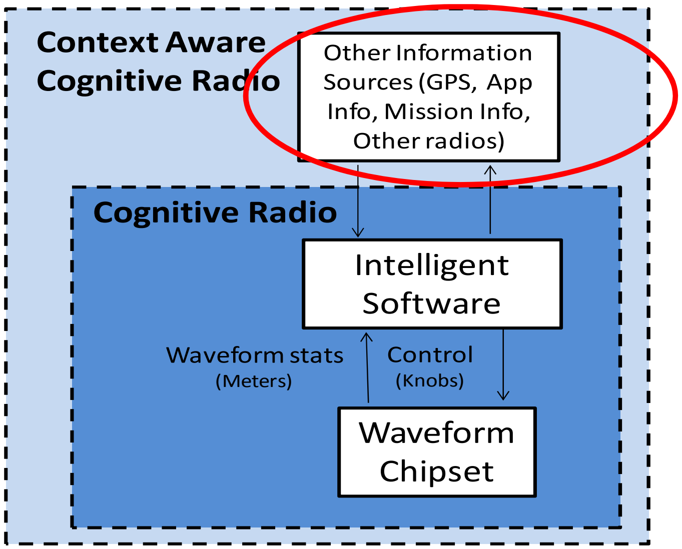




Research Opportunities / Needs

- Extensible languages for modeling and reasoning on contextual information
- Appropriate mechanisms for assessing context
- Sharing context
- Programming languages for network managers
- User-interface for feedback
- Contextual pattern recognition
- Tools for automating the creation and updating of context models

Gimbal? RSCM?



- Applying context information to control wireless chipsets
- Big Data Tools applicable to RF problems

Call for Participation in CRWG Context Effort

- **Interdisciplinary effort**
  - Benefits from insights from many different backgrounds
- **Project Meeting at Conference on Wednesday**
  - 10:00-12:30 Room T4 (local time)
  - 14:00-15:30 Room T4 (local time)
- **Web Meetings**:
  - Wednesdays 11:30 AM-12:30 PM Eastern
  - https://www1.gotomeeting.com/join/950203273
  - Dial +1 (773) 897-3008
  - Access Code: 950-203-273