

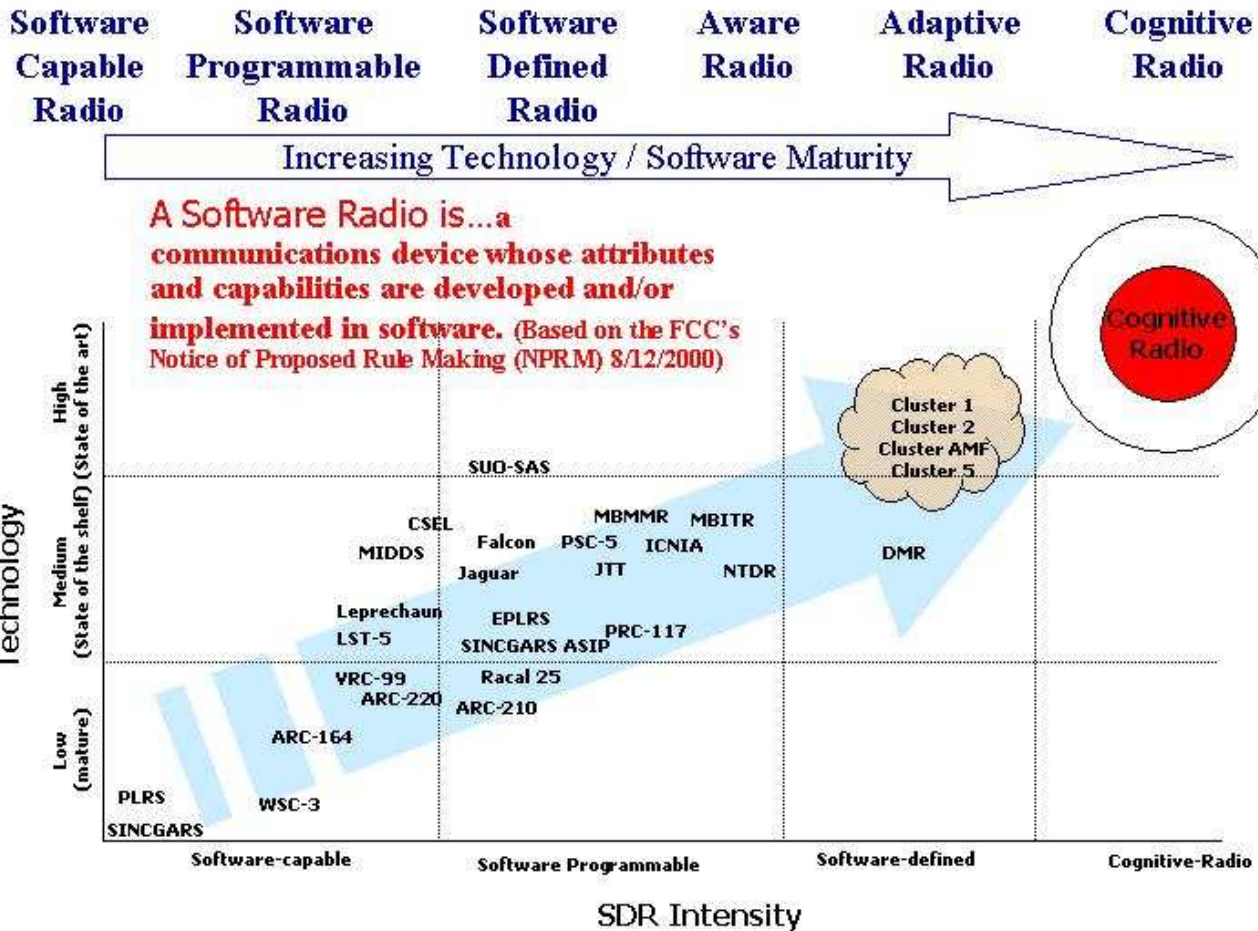
COGNITIVE RADIO APPLICATIONS IN SOFTWARE DEFINED RADIOS

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Cognitive Radio Enabling Technology

- **General Purpose RF Technology**
 - Wide Coverage
 - “Wide” Instantaneous Bandwidth
- **General Purpose Digital Processing (Distributed)**
 - FPGA
 - DSP
 - GPP
- **Artificial Intelligence Technology**
 - Sensors
 - Actuators
 - Agent Models

Continuum of Radio Capabilities Leading to Cognitive Radio



Cognitive Radio Characteristics*

- **Sensors creating awareness in the environment**
- **Actuators enabling interaction with the environment**
- **Memory and a model of the environment**
- **Learning and modeling of specific beneficial adaptations**
- **Specific performance goals**

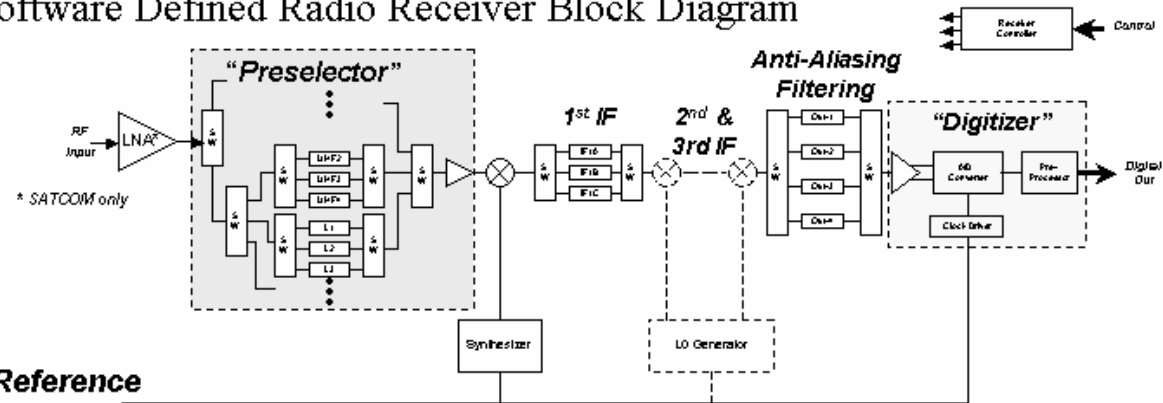
*SDRF CRWG: Heuristic Radio

RF Frontend (superhet architecture)

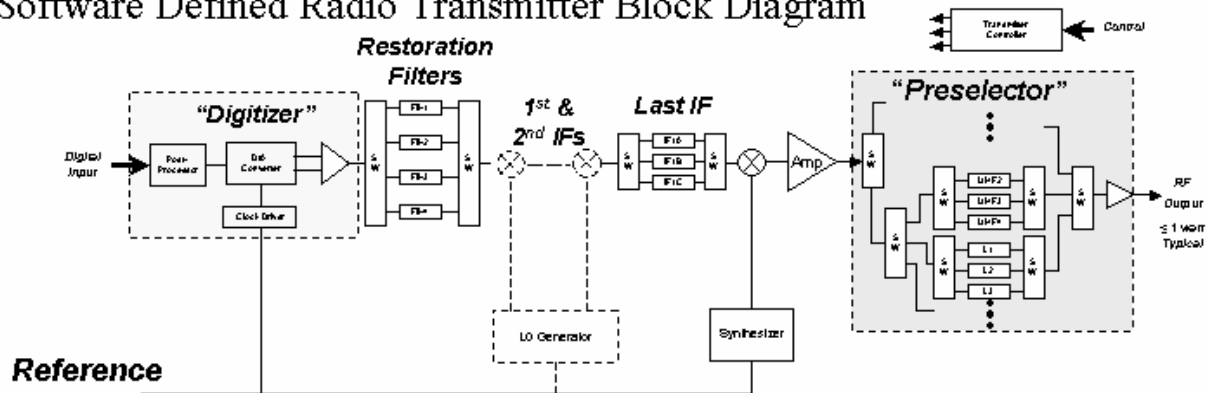
- **Preselector / Power Amplifier**
 - Coverage
 - Range
- **Transmit Chain**
 - Instantaneous BW
 - Dynamic Range
- **Receive Chain**
 - Instantaneous BW
 - Dynamic Range
- **Synthesizer**
 - IF Frequencies
 - Stability etc.

General SDR RF Frontend

Software Defined Radio Receiver Block Diagram



Software Defined Radio Transmitter Block Diagram



Classes of Processing Resources

- **FPGA**

- High sample rate
- Highly concurrent computations
- Reconfigurable

- **DSP**

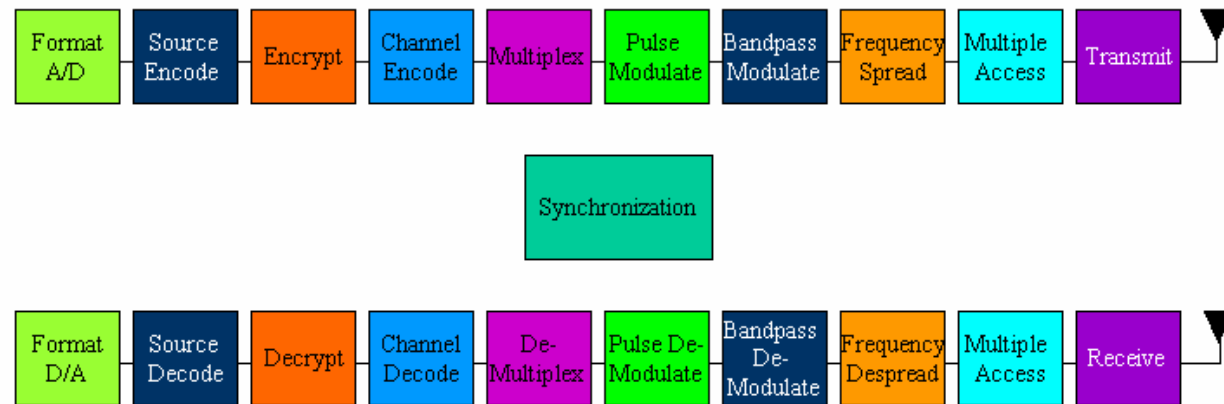
- Low power
- Low cost
- Good Multiply Accumulate performance

- **GPP**

- Good for protocol stacks
- Good for Artificial Intelligence Applications

*Cryptographic Processors
Needed in Some Military
Applications*

MODEM Block Diagram & Resources



FPGA Processing Resources

- High Sample Rate
- Highly Parallel Computations
- HDL Specifications for Images
- Fixed Point Arithmetic (Primarily)

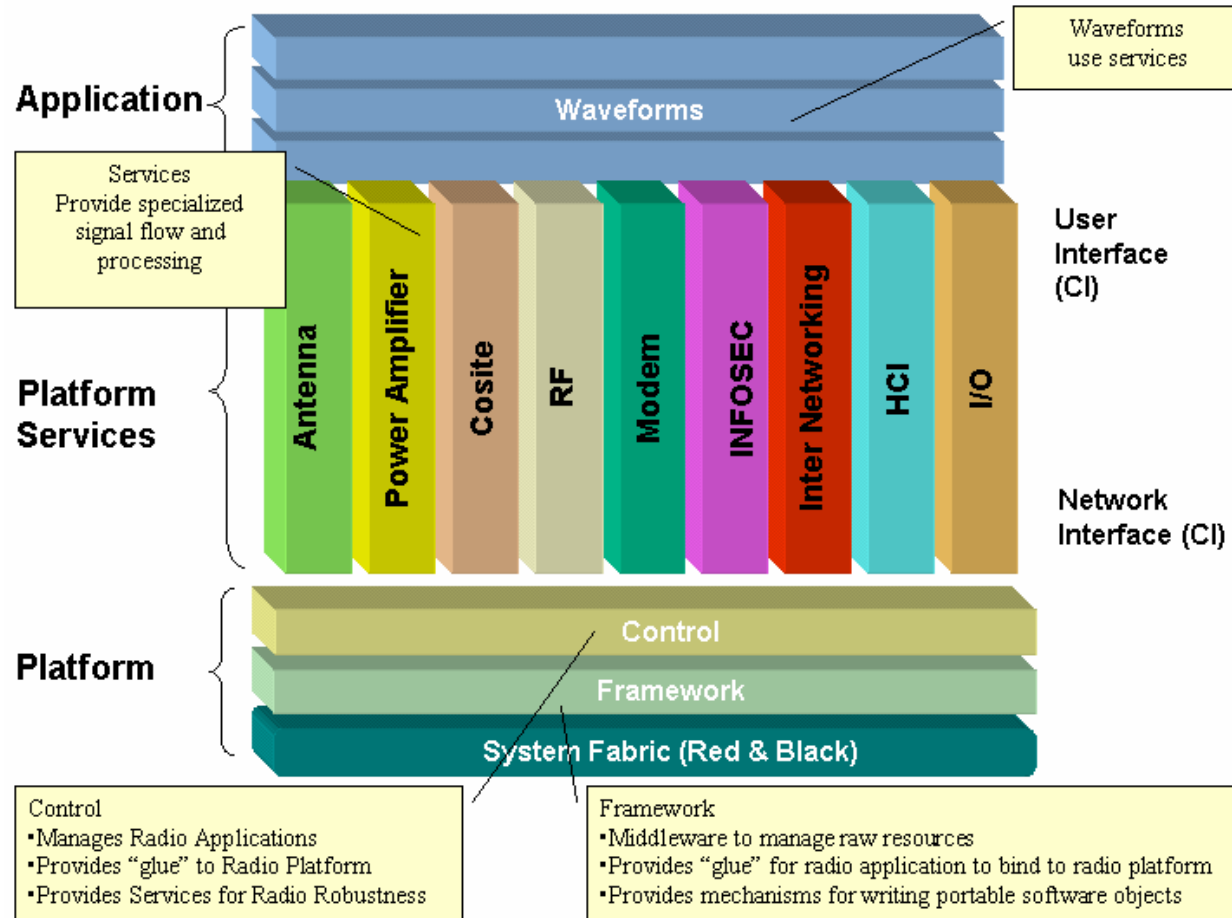
DSP Processing Resources

- Lower Sample Rates
- Sequential Computations
- Code Defined Processing
- Fixed or Floating Point Arithmetic (Depends on Parts Selection)

Software Architecture

- **Layered**
- **Standard Interfaces**
 - POSIX RTOS
 - CORBA if Software Communication Architecture Compliant

SDR Software Architecture



Smart Agents

- **Simple Reflex Agent**

- Maps Inputs to Outputs
- Aware Application / Radio

- **Reflex Agent With State**

- Has Memory
- Adaptive Application / Radio

- **Goal-Based Agent**

- Model of Environment
- Minimum Requirement for Cognitive Application / Radio

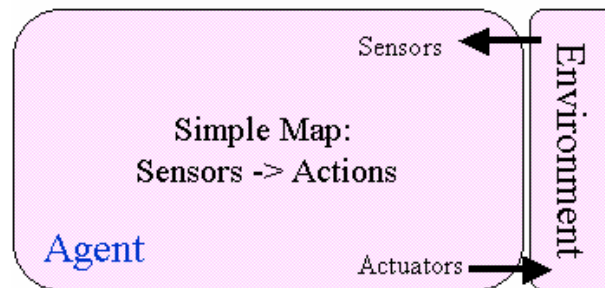
- **Utility-Based Agent**

- Model of Environment
- Utility / Judgment Function

Smart Agent Architectures

Simple Reflex Agent

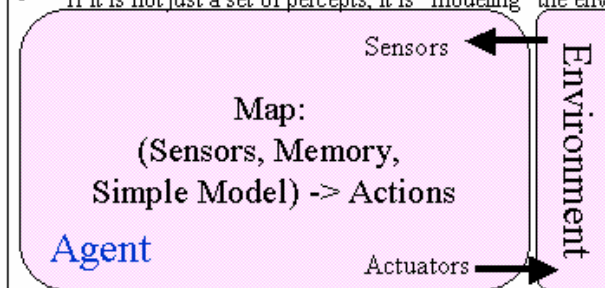
- Agent selects its action as a function of the current percept
- Combinational logic



Reflex Agent With State

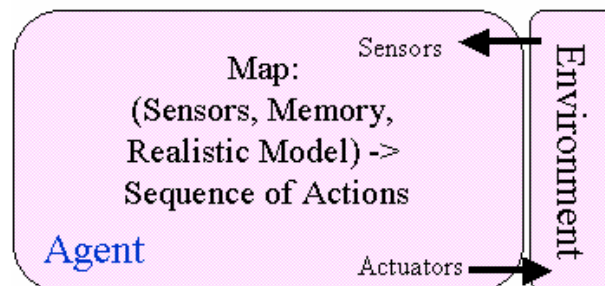
AKA Model-Based Reflex Agents

- Agent maintains internal state (memory) as a function of percept history and partially reflects unobserved aspects
- If it is not just a set of percepts, it is "modeling" the env.



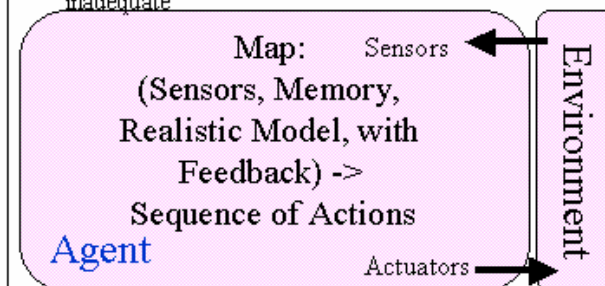
Goal-Based Agents

- Goal information identifies states that are desirable
- Simple: Single step reaches goal(s)
- Complex: Sequence of steps required to reach goal(s)



Utility-Based Agents

- Utility function maps state sequence to real number
- Real number is the relative happiness of the agent
- Allows rational decisions in some cases where goals are inadequate



Searching for A Solution

- **Given a Model of the Environment, What Actions Take the System To A Desirable Outcome**
- **State Space Searching Algorithms**
 - Breadth First Search
 - Depth First Search
 - Depth Limited Search
 - Iterative Deepening Depth First Search

Common State Space Search Algorithms

- Breadth First Search

A, B, C, D, E, F, G, H, I, J, K, ...

- Depth First Search

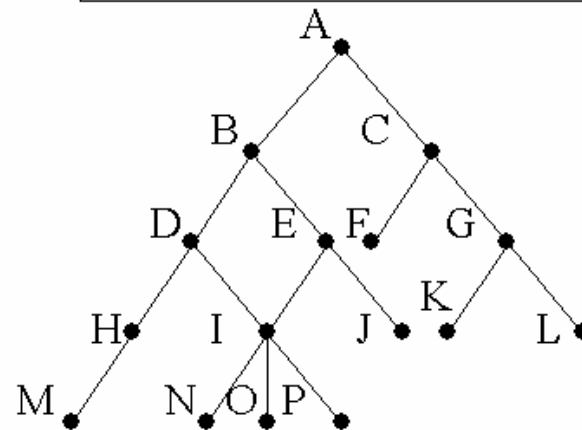
A, B, D, H, M, I, N, O, P, E, J, C, ...

- Depth Limited Search (level 0 – 3)

Does not search M, N, O, & P

- Iterative Deepening Depth First Search

A, B, D, E, C, F, G, H, M, I, N, O, P, J, K, L



Sensors and Actuators

Sensors

- RF
- Acoustic
- HMI
- Biometric
- Camera (still or motion)
- Geolocation
- Chemical

Actuators

- RF
- Aural
- HMI

Spectrum Awareness Applications

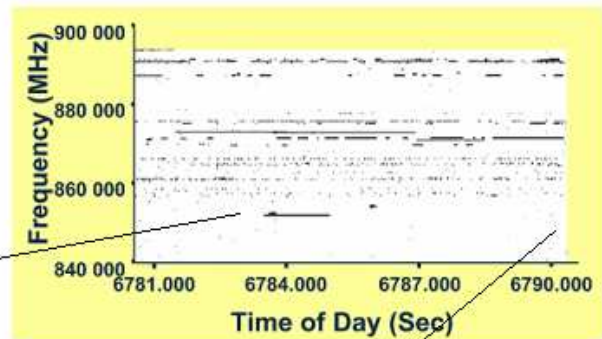
- **Low Spectrum Occupancy**
- **Spectrum Policy Task Force Recommendations**
- **Spectrum Harvesting And Rendezvous**
- **Policy Controls**
- **Sensors**
- **Non-interference**

Spectrum Awareness Applications

Spectrally Aware

- *Channel Activity statistics*
- *Usage Policies*
 - Lockouts, rentals, unlicensed

Regulators Will Define Spectrum Blocks Subject To Cognitive Radio Commons Etiquette and Who Is Allowed to Use



7% - 14% occupied spectrum



Deployed waveforms

Existing Signals

Detailed Signal Parameters

Geo-location & Networking Applications

- **Reporting (function of position)**
 - Blue Force Tracking
 - Teenager Tracking
 - Others
- **Networking**
 - Location of Services
 - Location Augmented Routing
 - Policy Changes as Function of Position

Location Awareness Applications

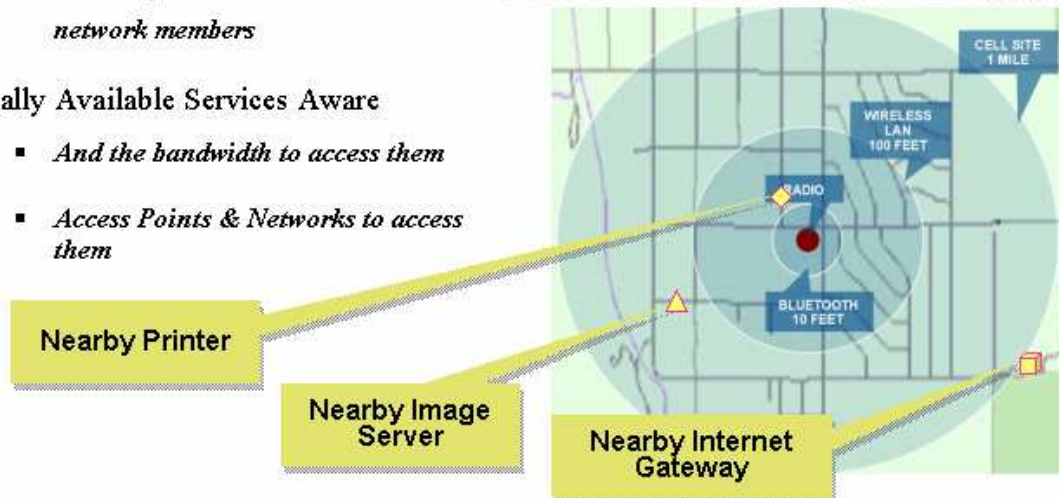
Geographically Aware

- *Local Policies*
- *Local Transmitters*
- *Local receivers*
- *Local terrain*
- *Local propagation channel*
- *Current position all network members*



Locally Available Services Aware

- *And the bandwidth to access them*
- *Access Points & Networks to access them*



Authentication

- **Voice Print**
- **Video**
- **Biometric**

Biometric Authentication Applications

Biometrics In Order of Effectiveness

1. Palm Scan
2. Hand Geometry
3. Iris Scan
4. Retina Scan
5. Finger Print
6. Voice Print
7. Facial Scan
8. Signature Dynamics
9. Keyboard Dynamics

Biometrics In Order of Social Acceptability

1. Iris Scan *
2. Keyboard Dynamics
3. Signature Dynamics
4. Voice Print **
5. Facial Scan *
6. Finger Print ***
7. Palm Scan ***
8. Hand Geometry ***
9. Retina Scan *



A Cognitive Radio may authenticate a user through a variety of biometric measures. Traditional handsets (left) may be modified to capture the necessary inputs for redundant biometric authentication.

* Requires a camera sensor

** Utilizes a copy of the voice input (low impact)

*** Requires a Sensor in the PTT Hardware

Planning Applications of the Future

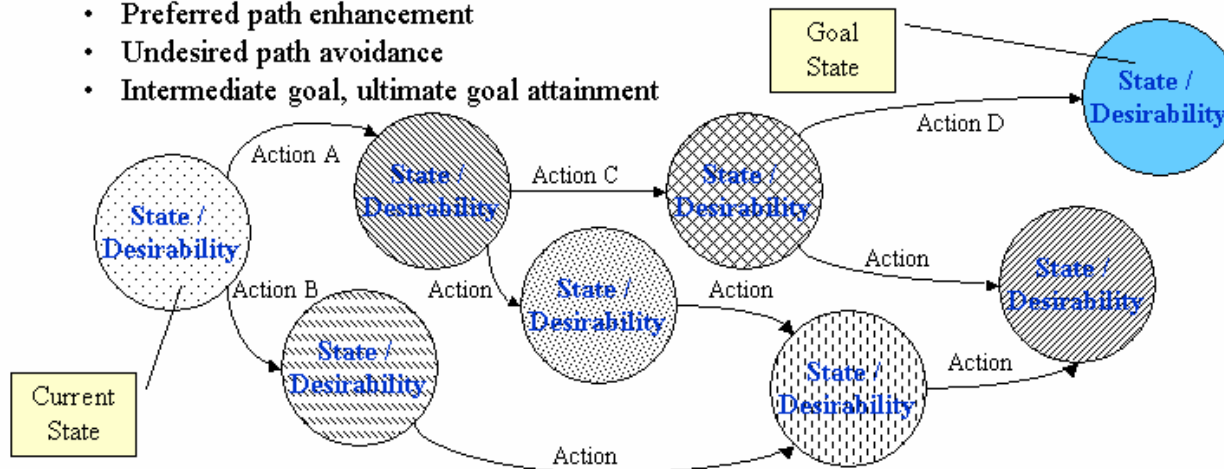
- **Navigation / Route Planning**
- **Battery Management**
- **Noise and Light Discipline**
- **Information Flow Planning**
- **Role Assignment as Function of operator's skills**
- **Talk Group Assignment**
- **Smart Calibration**
- **Smart Bridging**

Planning Applications

Planning => a sequence of actions enabling a problem solver to accomplish a specific task

- Robotics Applications
- Expert Systems *
- Natural Language Understanding *
- * Natural extension for Cognitive Radio Applications

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- Position Planning
 - Time vs. position trajectory
 - Threat vulnerability
 - Task capability
 - Progress vs. Plan Monitoring
 - Preferred path enhancement
 - Undesired path avoidance
 - Intermediate goal, ultimate goal attainment
 - Radio Performance Planning
 - Network connectivity changes
 - Link quality / QoS changes
 - Channel Multipath, Doppler, Interference and noise changes



Conclusions

- **Cognitive Radio Technology is enabled by:**
 - General Purpose RF Sections
 - High Powered Digital Computation Engines
 - Artificial Intelligence Technology
 - **Multiple Cognitive Radio Applications Are Of Interest**
 - Spectrum Access
 - Geo-location and Networking
 - Authentication
 - Planning
 - **Cognitive Radio Applications are on the horizon**
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