

Cognitive Systems

High Performance Embedded Computing Workshop

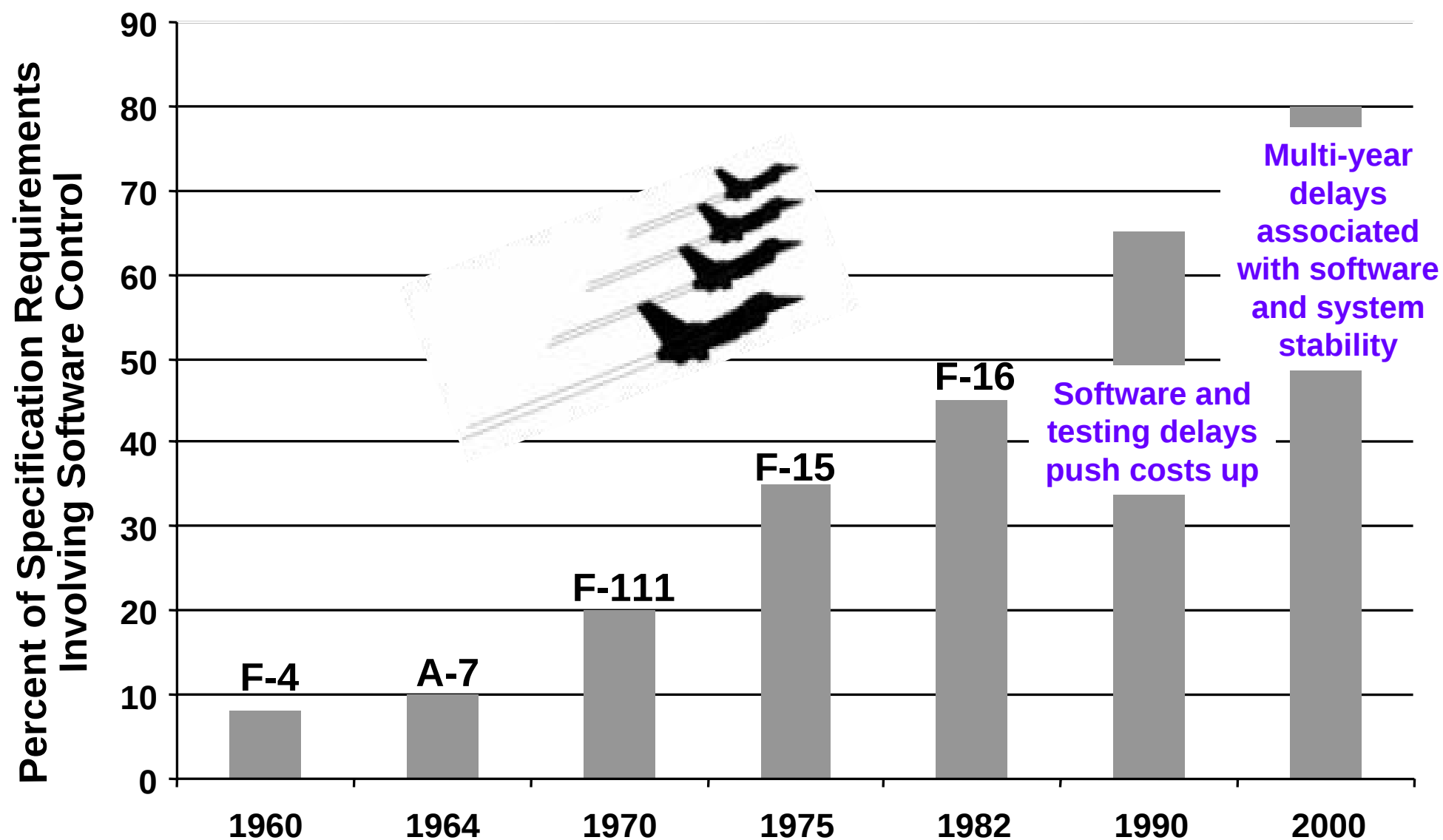
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- **Computer systems are the backbone of key national infrastructure and critical DoD systems**
 - Virtually all important transactions involve massive amounts of software and multiple computer networks
 - DoD future vision is “network-centric warfare”
- **While *computational performance* is increasing, productivity and effectiveness are not keeping up**
 - Cost of building and maintaining systems is growing out of control
 - Systems have short lifespans with decreasing ROI
 - Demands on expertise of users are constantly increasing
 - Users have to adapt to system interfaces, rather than vice versa
- **As a result, systems have grown more complex, more fragile, and more difficult to develop**

We need to change the game

Capability Provided by Software in DoD Systems is Increasing but so are the Challenges...



Developing Cognitive Systems: *Systems that know what they're doing*

- A cognitive system is one that
 - can **reason**, using substantial amounts of appropriately represented knowledge
 - can **learn** from its experience so that it performs better tomorrow than it did today
 - can **explain** itself and **be told** what to do
 - can be aware of its own capabilities and **reflect** on its own behavior
 - can **respond robustly** to surprise

- **...reflect on what goes wrong when an anomaly occurs and anticipate its occurrence in the future**
- **...respond to naturally-expressed user directives to change behavior or increase functionality**
- **...be configured and maintained by non-experts**
- **...reconfigure themselves in response to environmental changes and mission events**
- **...reduce the effort to develop and maintain software**
- **...thwart adversarial systems that don't know what they're doing**
- **...preserve “corporate memory” to ease transitions for rotational personnel**

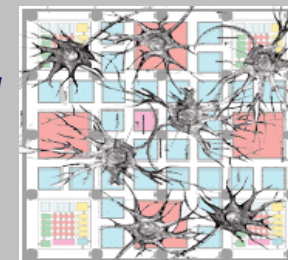
Systems That Know What They're Doing

What's Next?

- Intelligent Systems
 - - Architectures for Cognitive Information Processing (ACIP)

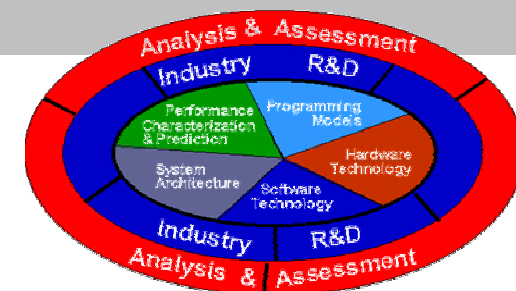


+ Cognitive Processing
Hardware Elements
SBIRs



- High-End Application Responsive Computing
 - High Productivity Computing Systems Program (HPCS)

HPCS + HECURA

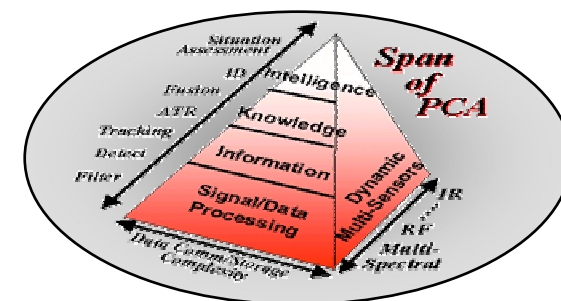


- Mission Responsive Architectures
 - Polymorphous Computing Architectures Program (PCA)

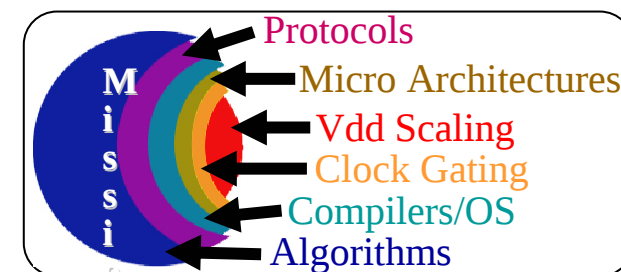
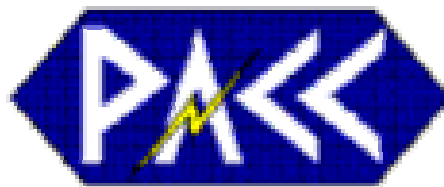


+ OneSAF
Objective System

+ XPCA??

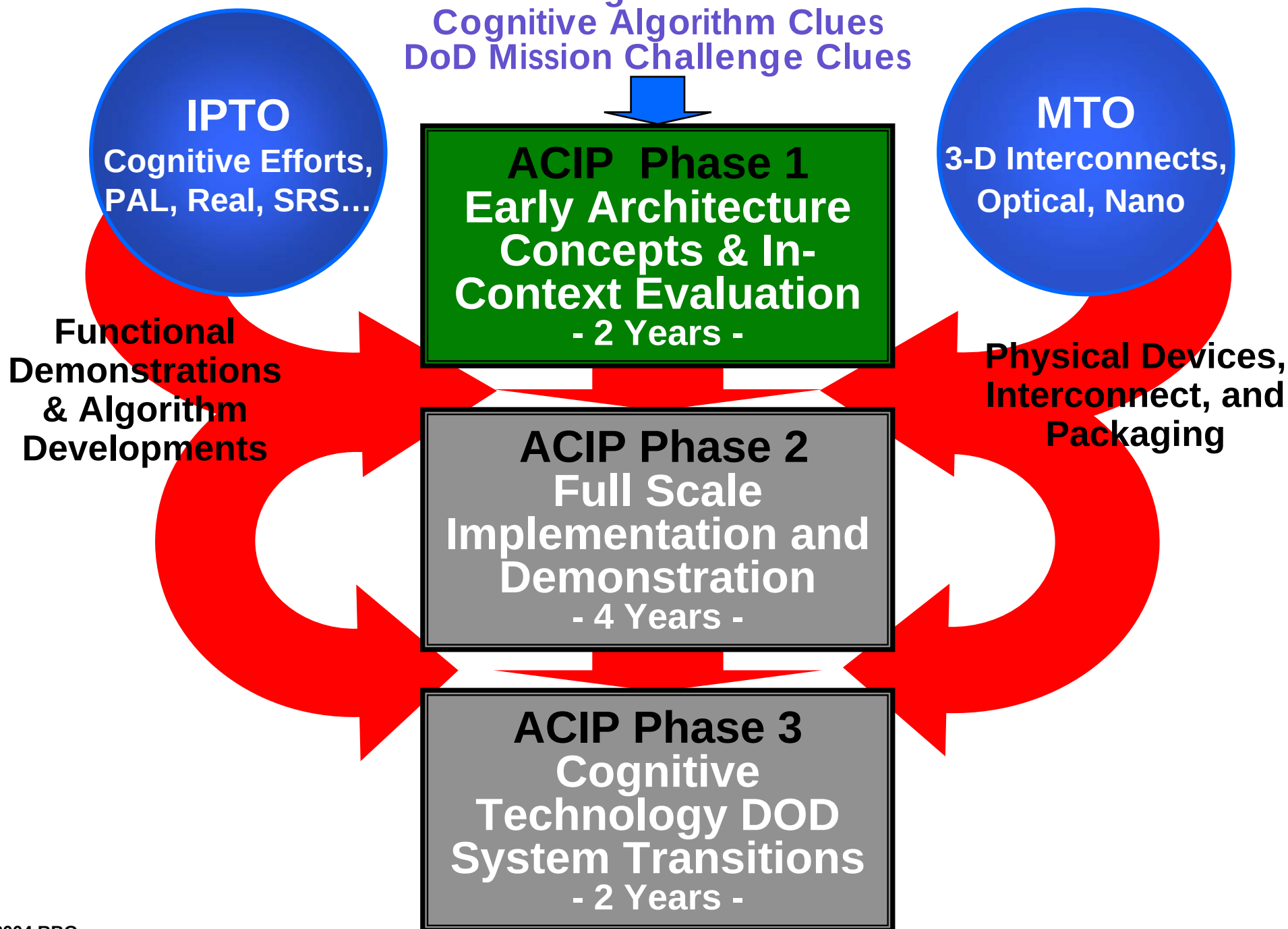


- Power Management
 - Power Aware Computing and Communications Program (PAC/C)



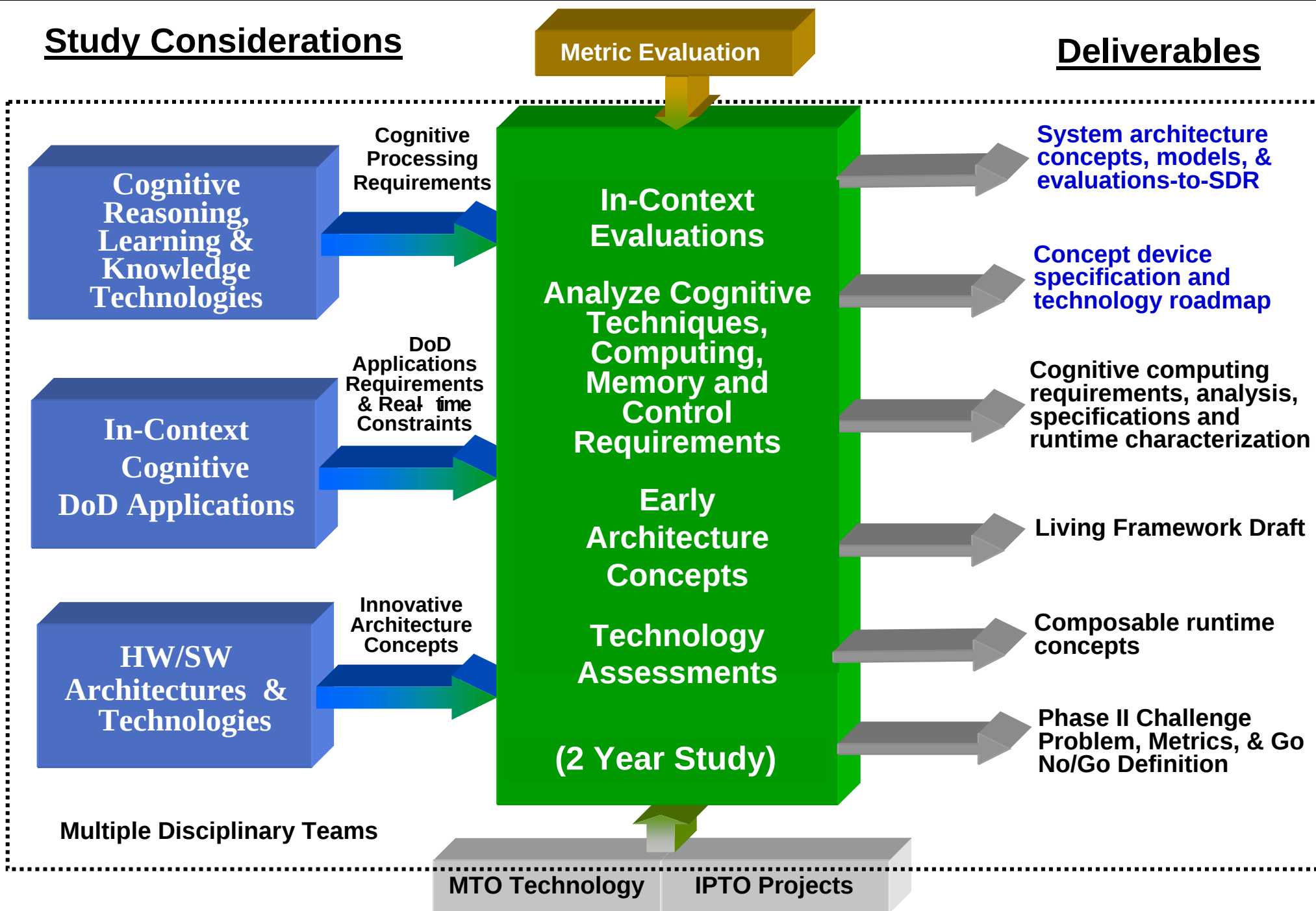
ACIP Program Vision

Biological Clues
Cognitive Algorithm Clues
DoD Mission Challenge Clues



Study Considerations

Deliverables



- **Fantastic Response!!!**
- **Participation Mix (Including Subs)**
 - **9 Defense Contractors**
 - **11 Research Laboratories**
 - **51 Universities**
 - **30 Commercial Companies**

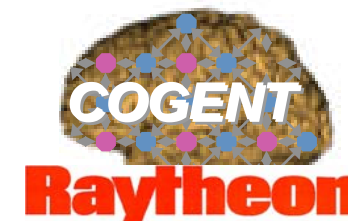
Broad Multi-Disciplinary Coverage required for System Innovation

Large Diverse and Robust Teams Resulted in the Best Concepts

Study Technical Framework Concept has Emerged

- **COGnitive ENGine Technology (COGENT)**

- Raytheon Company - Network Centric Systems



- **Polymorphous Cognitive Agent Architecture (PCAA)**

- Lockheed Martin Advanced Technology Labs



- **CEARCH: Cognition Enabled Architecture**

- University of Southern California/ISI



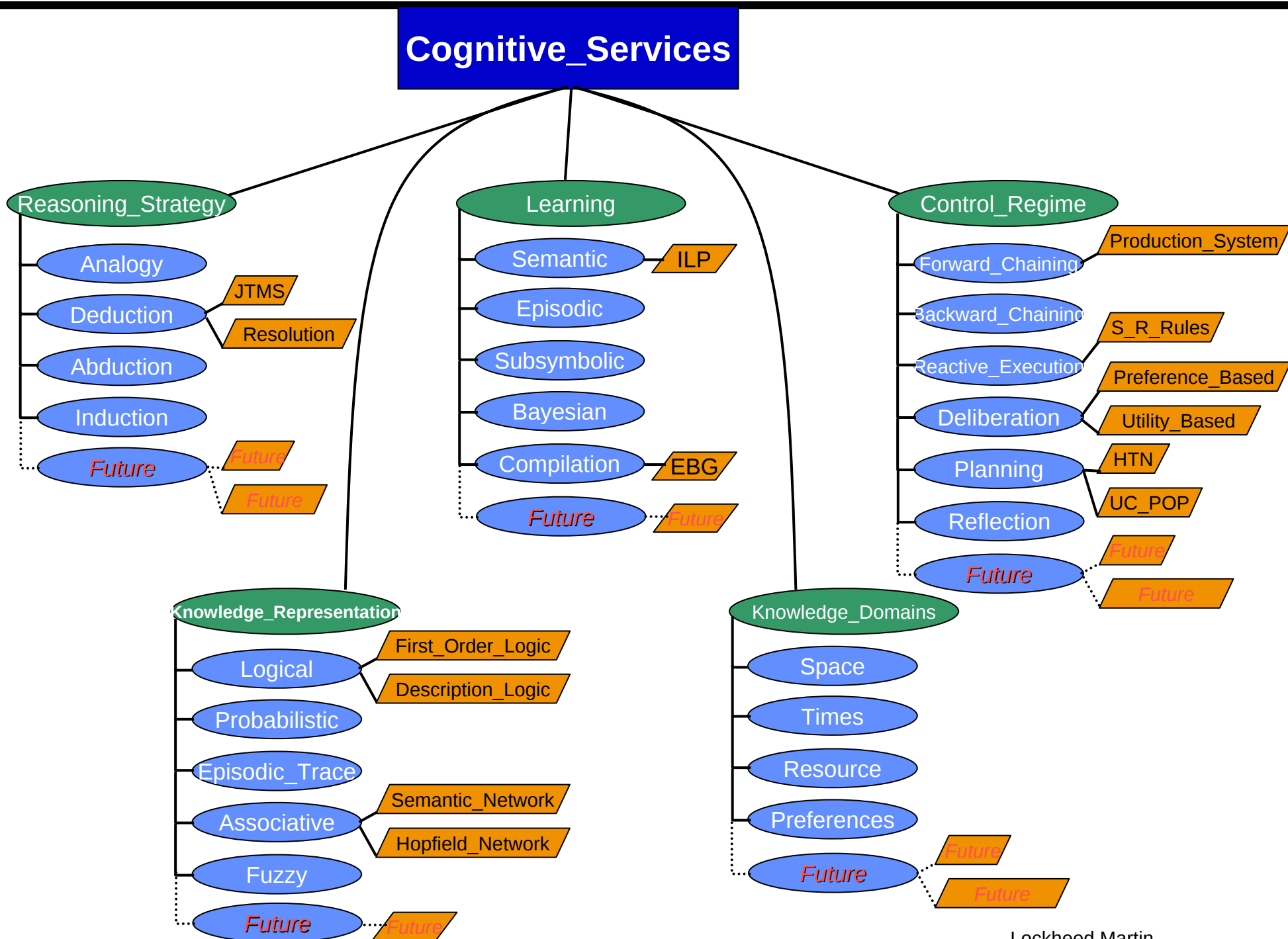
- **Reservoir Labs Inc – Cognitive Processing Hardware and Software elements**
- **Intelligent Automation Inc. – Hardware Architectures for Flexible Component Based Hybrid Cognitive Systems**
- **Hoplite Systems LLC – Cognitive Processing Hardware Elements**
- **Cardinal Research LLC – Cognitive Processing Hardware Elements**
- **Saffron Technologies – Associative Memory Hardware Elements for Cognitive Systems (Funded by AFRL)**

Cognitive Technology Classification

Reasoning Algorithms	Symbolic (S) Probabilistic (P) Hybrid (H)	Ray	LM	ISI
1st Order Reasoning	S		X	
Abductive Reasoning	S,P,H	X	X	
Analogical Reasoning	S,H	X		
Bayesian Networks	P			
Case-based Reasoning	S,H			
Causal Reasoning	P	X		
Common Sense Reasoning	S	X		
Counterfactual Reasoning	S			
Deductive Inference	S	X		
Defeasible Reasoning	H		X	
Forward & Backward Chaining	S			
Fuzzy Reasoning	H		X	
Game Theory - Optimization	H			
Goal-oriented Planning	S			X
Heuristic Meta-reasoning	H			X
Inductive Reasoning	S		X	
Logical Pattern Matching	S			
Logical Unification	S			
Markov Processes	P			
Mathematical Programming	H			
Maximum Likelihood	P	X		
Meta-meta Reasoning	S			X
Modal Intuitionistic, Higher Order Reasoning	S		X	
Model-based Reasoning	H	X		
Non-monotonic Reasoning	S			
Optimal decisions - Min-Max, Auctions	P	X		
Pattern Matching	H			
Probabilistic Constraint Satisfaction	H	X	X	X
Resource-limited Theorem Proving	S		X	X
SAT - Constraint Satisfaction	S	X		
Special Purpose Reasoning Algorithms	S			X
Temporal Reasoning	S,P,H	X		
Utility Theory	P	X		
Well-formedness Reasoning	S			X

Learning Algorithms	Symbolic (S) Probabilistic (P) Hybrid (H)	Ray	LM	ISI
Abductive Learning	H		X	
Abstraction	H	X		
Analogical Learning	S			X
Artificial Neural Networks	P		X	
Associative	H	X		
Bayesian Learning	P		X	
Chunking	H	X		
Classification Learning	H			
Clustering	P,H	X		
Constructing Analogies	S	X		
Co-training	H			
Data Mining	H			
Decision Trees	H		X	
Dimensionality Reduction	H			
Evolutionary Search	H			X
Genetic Algorithms	P		X	
Inductive Learning	S		X	
Instance-based Learning	P		X	
Learning from Advice	H	X		
Network Construction	P			
Parameter Learning	P	X		
Plan recognition	H			
Reinforcement Learning	P,H	X	X	X
Relational Learning	S	X		
Rule Generation Composition & Specialization	S			
Statistical Clustering	P		X	
Statistical Learning (nearest neighbor, approx)	P			X
Supervised Learning	P			X
Support Vector Machine	P	X		

Knowledge Representation Algorithms	Symbolic (S) Probabilistic (P) Hybrid (H)	Ray	LM	ISI
1st Order Logic (with extensions)	S	X		X
Bayesian Classifier	P			
Bayesian Networks	P,H	X		
Case -based	S			X
Causal Networks	H	X		
Conceptual Graphs	H	X		
Decision Trees	H	X		X
Episodic	H		X	
Frames	H	X		
Fuzzy Logic	H		X	
Horn Clause Program	S			
Influence Diagrams	H	X		
Knowledge Acquisition	H			
Logical (Prop., FOL, Frame-based)	S			
Logical Rules	S		X	
Markov Models	P	X		X
Multi-layer Neural Net	P			
Ontologies	H	X		X
Production System	S			
Propositional Logic	H	X		
Reactive Plan	S			
Relational Models	H	X		
Rule-based Systems	H			
Self-knowledge	H			
Semantic Nets	S			
Situation Calculus	S	X		
Taxonomic Hierarchy	P			
Temporal Networks	H	X		
Type Ontologies and Constraints	S			X



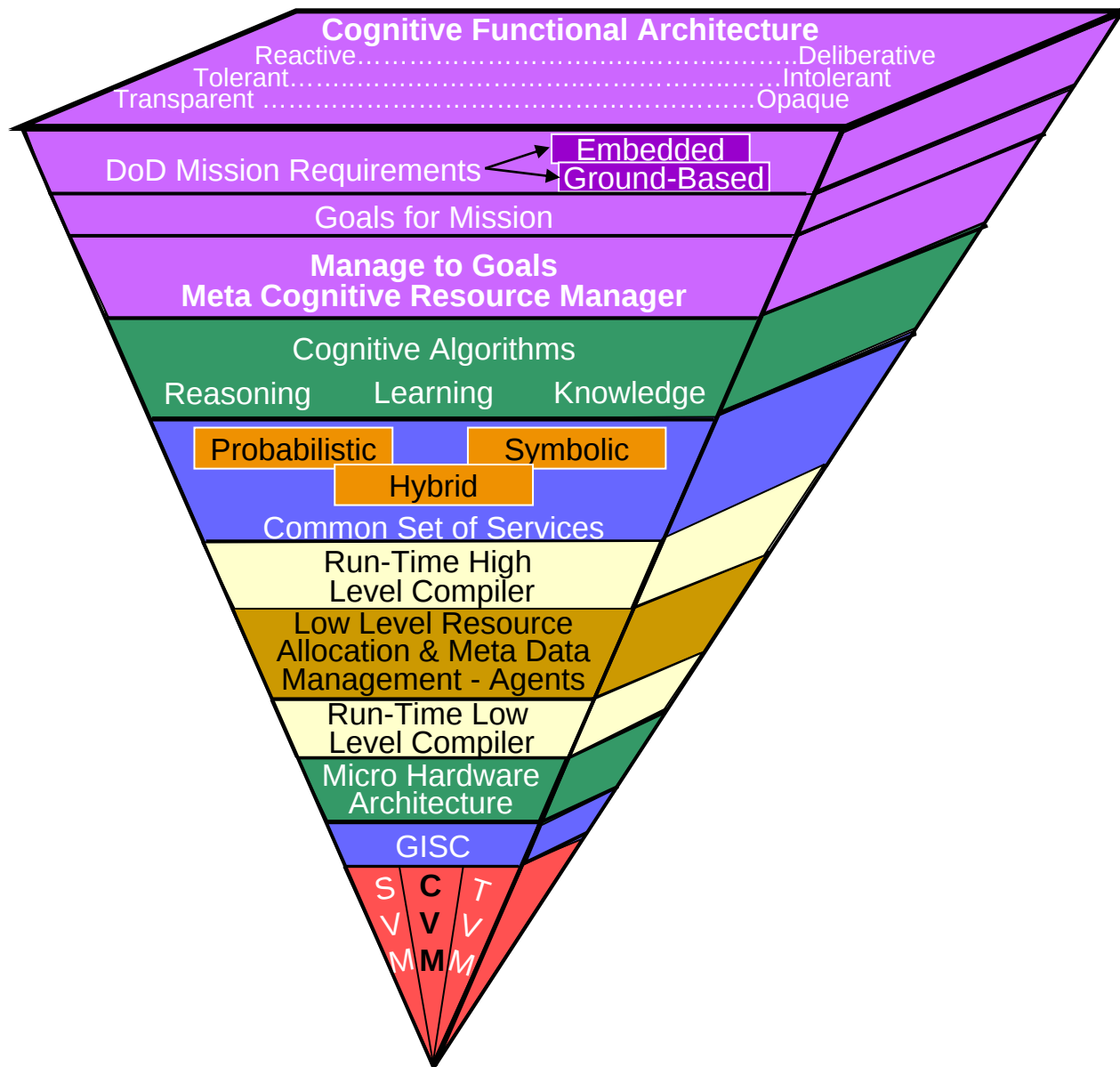
Cognitive Computing Requires Innovation

Classical Computing

- ❑ Markovian –current state only
- ❑ Processor-oriented; favors regular addressing
- ❑ Procedural, results oriented – apply this function next
- ❑ Key operations: arithmetic & simple scalar decision making
- ❑ Single deterministic result
- ❑ Parallelism difficult to extract
- ❑ Functional composition determined at compile time
- ❑ Largely static resource management

Cognitive Processing

- ❑ History of prior results guides next: “learning”
- ❑ Memory-oriented; unpredictable access patterns, with metadata guiding access
- ❑ Goal oriented – with multiple, possibly incompatible objectives,
- ❑ Process oriented – history + new perceptions => new knowledge
- ❑ Context oriented – computation based on metadata from prior results
- ❑ Key operations: wide spectrum including complex pattern matching
- ❑ Often multiple “acceptable” results
- ❑ Speculation, futures a first class activity
- ❑ Functional composition determined at run-time
- ❑ Dynamic resource management (Reasoning vs Learning Balance)



PCA (SVM+TVM) + CVM = ACIP???

Potential New Research Ideas!

Leveraging Embedded Computing Workshop Ideas

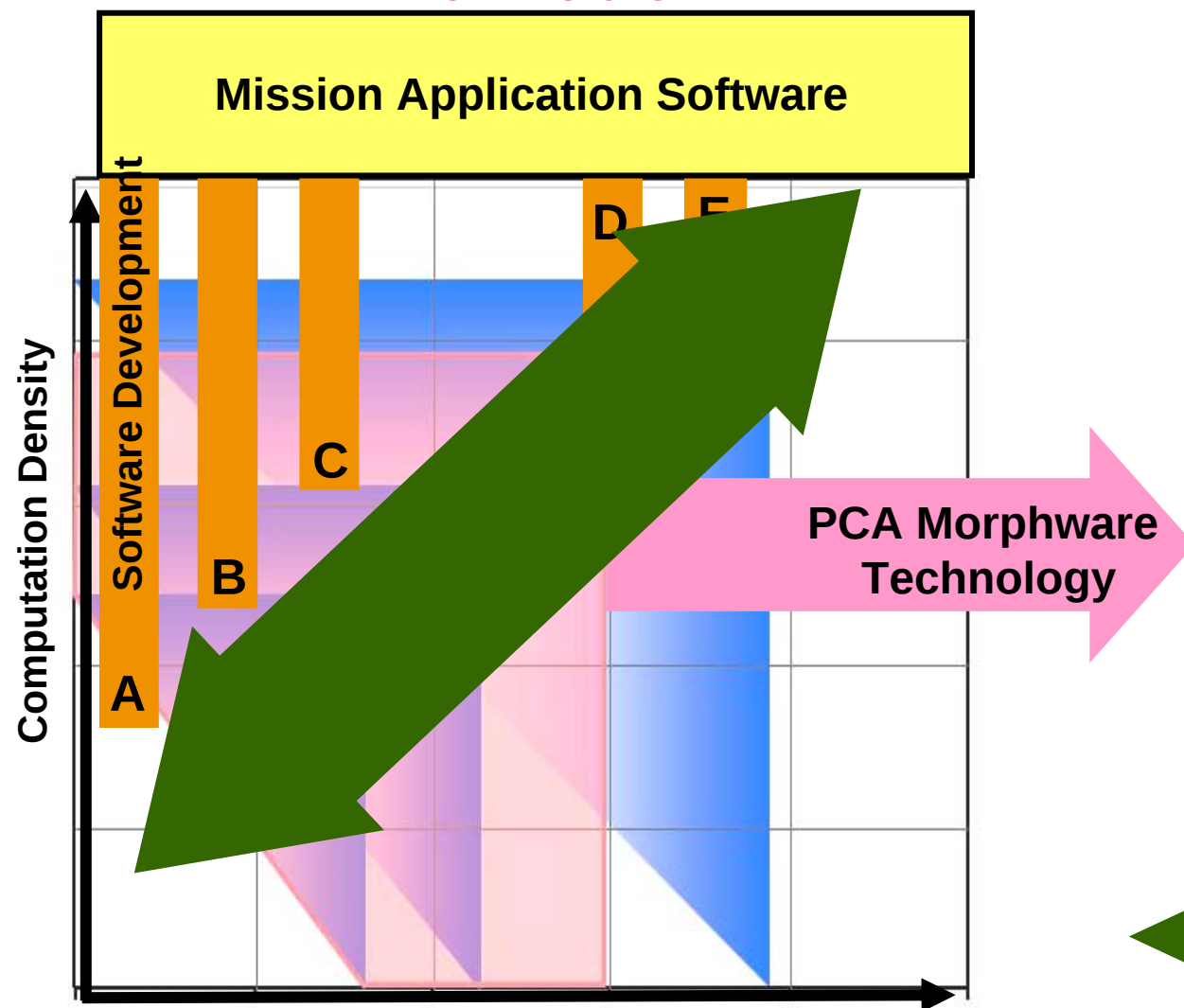
Chaired by

MIT LL and ISI

Future Role of Embedded Computing Devices:

GP, DSP, GPU, NIC, FPGA, ASIC

The Problem



The Solution



Manual Low Visibility Stove Pipe
SW Development Environments

- Developed under PCA program
- Physical (COTS) PCA Systems Concept

Embedded Computing Complexity Challenge

Embedded Software Developer

**The Solution:
Cognitive Software Developer's Assistant**

Cognitive SW Development & Runtime Assistant

War Fighter

Mission Software

High Level Software Development Environment

Stable Architecture Abstraction Layer (SAAL)

SVM

TVM

DTVM

X

Low Level Device Vendor Specific

Game Chips

FPGA

PCA

GPU & NICs



Developed under PCA program

The Future is Yours

**Become an DARPA Program
Manager!!**