Cognitive Systems

High Performance
Embedded Computing Workshop

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The Challenge

- 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...

Ref: Defense Systems Management College

Multi-year delays associated with software and system stability

Software and testing delays push costs up

Percent of Specification Requirements Involving Software Control


F-4 A-7 F-111 F-15 F-16

F-22
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
Computing Systems that know what they’re doing can…

- …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
Four Tiers of Agile Processing

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

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

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

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

What’s Next?

Systems That Know What They’re Doing

- Cognitive Processing Hardware Elements SBIRs
  - Objective System
  - OneSAF
  - XPCA??

- Power Management Protocols
  - Micro Architectures
  - Vdd Scaling
  - Clock Gating
  - Compilers/OS Algorithms
ACIP Program Vision

ACIP Phase 1
Early Architecture Concepts & In-Context Evaluation
- 2 Years -

ACIP Phase 2
Full Scale Implementation and Demonstration
- 4 Years -

ACIP Phase 3
Cognitive Technology DOD System Transitions
- 2 Years -

Biological Clues
Cognitive Algorithm Clues
DoD Mission Challenge Clues

IPTO
Cognitive Efforts, PAL, Real, SRS...

MTO
3-D Interconnects, Optical, Nano

Functional Demonstrations & Algorithm Developments

Physical Devices, Interconnect, and Packaging
ACIP Phase I

Study Considerations

- Cognitive Reasoning, Learning & Knowledge Technologies
  - Cognitive Processing Requirements

- In-Context Cognitive DoD Applications
  - In-Context Evaluations
  - Analyze Cognitive Techniques, Computing, Memory and Control Requirements
  - Early Architecture Concepts
  - Technology Assessments
  - Living Framework Draft
  - (2 Year Study)

- HW/SW Architectures & Technologies
  - Innovative Architecture Concepts

Deliverables

- System architecture concepts, models, & evaluations-to-SDR
- Concept device specification and technology roadmap
- Cognitive computing requirements, analysis, specifications and runtime characterization
- Living Framework Draft
- Composable runtime concepts
- Phase II Challenge Problem, Metrics, & Go No/Go Definition

Multiple Disciplinary Teams

MTO Technology IPTO Projects
Fantastic Response!!!

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

Study Technical Framework Concept has Emerged
Funded ACIP Efforts

- 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
ACIP Related SBIRs

- 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)
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Cognitive Services

Reasoning_Strategy
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- Deduction
- Abduction
- Induction
- Future

Learning
- Semantic
- Episodic
- Subsymbolic
- Bayesian
- Compilation
- ILP
- EBG

Control_Regime
- Forward_Chaining
- Backward_Chaining
- Reactive_Execution
- Deliberation
- Planning
- Reflection
- Future

Knowledge_Representation
- Logical
- Probabilistic
- Episodic_Trace
- Associative
- Fuzzy
- First_Order_Logic
- Description_Logic
- Semantic_Network
- Hopfield_Network

Knowledge_Domains
- Space
- Times
- Resource
- Preferences
- Future
## 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)
ACIP Strawman Framework

DoD Mission Requirements
- Embedded
- Ground-Based

Goals for Mission

Manage to Goals
- Meta Cognitive Resource Manager

Cognitive Algorithms
- Reasoning
- Learning
- Knowledge

Common Set of Services
- Probabilistic
- Symbolic
- Hybrid

Low Level Resource Allocation & Meta Data Management - Agents

Run-Time Low Level Compiler

Run-Time High Level Compiler

Micro Hardware Architecture

GISC

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
Physical (COTS) PCA Systems

The Problem

- Mission Application Software
  - Software Development
    - A
    - B
    - C
  - Computation Density

The Solution

- War Fighter
  - Mission Software
  - PCA Morphware Technology
  - Developed under PCA program
  - Physical (COTS) PCA Systems Concept

Manual Low Visibility Stove Pipe
SW Development Environments
Software Developer’s Assistant

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!!