Autonomous Horizons

System Autonomy in the Air Force

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24 March 2016
San Diego, CA

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Outline

- **Background and context**
- **Challenges to overcome**
- **Approaches to solutions**
- **Next steps**

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Previous Offset Strategies

- **1st Offset: President Eisenhower's "New Look"**
  - **In the 1950s, introduced tactical nuclear weapons to match Soviet numerical and geographical advantage along German border**
  - **Key investments: Expanded aerial refueling, enhanced air/missile defense networks, solid-fueled ICBMs, and passive defenses (eg, silos)**
- **2nd Offset: SecDef Harold Brown's "Offset Strategy"**
  - **In the 1970s to a growing Soviet nuclear arsenal forced a shift by US to non-nuclear tactical advantage**
  - **Key investments: new ISR platforms and battle management capabilities, precision-strike weapons, stealth aircraft, and tactical exploitation of space (eg, GPS)**
- **3rd Offset: ???**

Davy Crockett

Lockheed F-117 Nighthawk

Center for Strategic and Budgetary Assessments, *Toward a New Offset Strategy: Exploiting U.S. Long-Term Advantages to Restore U.S. Global Power Projection Capability*, 2014

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8 Bands Selectable Man-

10 Antenna 10 Band 3G 4G GPS

15W 6 Antenna Mobile Phone GPS

20W Powerful Desktop GPS 3G

Current Top Sellers

Mini GPS jammer for Car
US$57.90

2 Mini GPS Satellite Isolator
US$64.99

3 Mini Portable Cell phone & GPS

I'm Offline

Leave a Message

Call for 2012 DSB Study on Autonomous Systems

THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

ACQUISITION, TECHNOLOGY AND LOGISTICS

MAR 2 9 2010

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference - Defense Science Board Task Force on the Role of Autonomy in Department of Defense (DoD) Systems

Dramatic progress in supporting technologies suggests that unprecedented, perhaps unimagined, degrees of autonomy can be introduced into current and future military systems. This could presage dramatic changes in military capability and force composition comparable to the introduction of "Net-Centricity." It is important that DoD understand and prepare to take maximum practical advantage of advan... this area. The timing is especially important as we introduce significant numbers of unman... systems into the force and perhaps limit their capability by imposing restraints associated with manned concepts upon the capabilities of new systems.

You are requested to form a Task Force that will inform the De...tment's plans in this area; specifically, the Task Force should:

- Review relevant technologies and ongoing research and development (Ra... of autonomous systems to evaluate the readiness of autonomous systems, or autonomy improvements, for introduction into DoD.
- Identify and review current plans of the Military Departments for the integration of autonomy in current or near-term systems and employment of next-generation autonomous systems and analyze missed opportunities.
- Assess the personnel training and force structure impacts of various improvements to autonomy, including opportunities, to reduce weapon system and associated personal forward footprint.
- Identify new opportunities for more aggressive application of autonomy to U.S. military materiel and the benefits this might provide to our military posture and the accomplishment of military missions.
- Comment upon the potential value of autonomy to both symmetric and asymmetric adversaries and, where possible, review available intelligence, and provide the basis for net assessment.

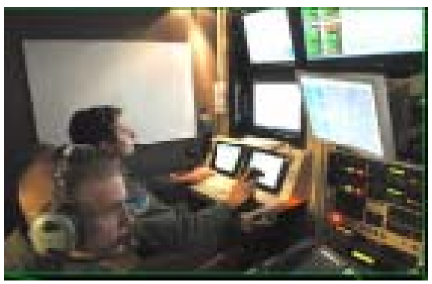
Dramatic progress in supporting technologies suggests unprecedented, perhaps unimagined, degrees of autonomy can be introduced into current and future military systems.

This could presage dramatic changes in military capability and force composition …

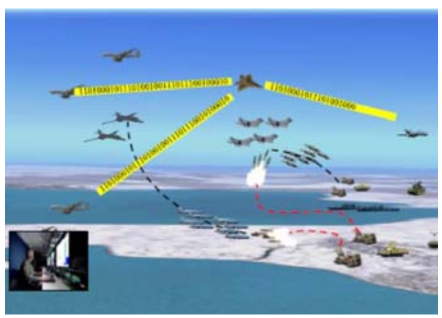
The timing is especially important as we introduce significant numbers of unmanned systems into the force …

DSB 2012 Autonomy Study Recommendations

- **The Assistant Secretary of Defense for Research and Engineering (ASD(R&E)) should work with the Military Services to establish a coordinated S&T program with emphasis on:**
  - **Natural user interfaces and trusted human-system collaboration**
  - **Perception and situational awareness to operate in a complex battle space**
  - **Large-scale teaming of manned and unmanned systems**
  - **Test and evaluation of autonomous systems**
- **These emphasis areas have driven DoD's Autonomy Community of Interest Tier I Technology Areas*:**

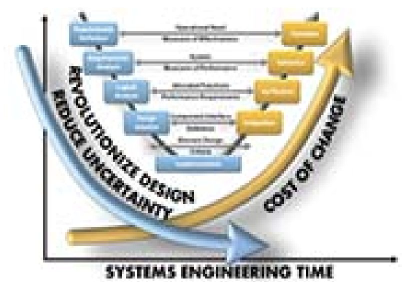


Human/Autonomous System Interaction and Collaboration (HASIC)



Machine Perception, Reasoning and Intelligence (MPRI)

Scalable Teaming of Autonomous Systems (STAS)



Test, Evaluation, Validation, and Verification (TEVV)

*Dr. Jon Bornstein, "DoD Autonomy Roadmap: Autonomy Community of Interest", NDIA 16th Annual Science & Engineering Technology Conference, Mar 2015.

Air Force Strategic Master Plan

- Provide 21st Century Deterrence
- Maintain Global ISR
- Ensure Full-Spectrum High-End Force
- Pursue Multi-Domain Approach to Core Missions
- Pursue Game-Changing Technologies
  - Hypersonics
  - Directed Energy
  - Nanotechnology
  - Unmanned Systems
  - Autonomous Systems

Air Force Strategy
"A Call to the Future"

Air Force Strategic Master Plan

Autonomy Could Transform Many Air Force Missions

Remotely Piloted Vehicles

Manned Cockpits

Space

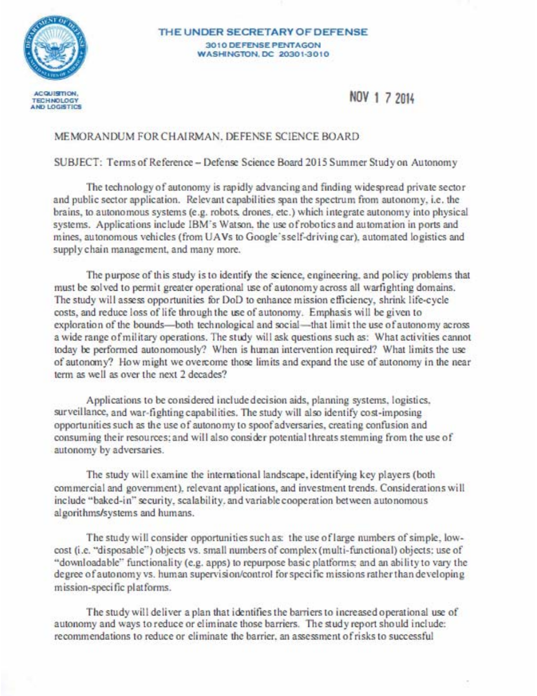
Cyber Operations

C2&ISR

Air Traffic Control

DSB 2015 Autonomy Study: Terms of Reference

- **The study will ask questions such as:**
  - **What activities cannot today be performed autonomously? When is human intervention required?**
  - **What limits the use of autonomy and how might we overcome those limits and expand the use of autonomy?**
- **The study will also consider:**
  - **Applications (eg, decision aids, ISR systems)**
  - **International landscape, identifying key players, applications, and investment trends**
  - **Opportunities such as:**
    - **Use of large numbers of simple, low cost (ie, "disposable") objects**
    - **Use of "downloadable'· functionality (e.g. apps) to repurpose basic platforms**
    - **Varying levels of autonomy for specific missions rather than developing mission-specific platforms**
- **The study will deliver a plan that identifies barriers to operationalizing autonomy and ways to reduce or eliminate those barriers**



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ACQUISITION, TECHNOLOGY AND LOGISTICS

NOV 1 7 2014

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference – Defense Science Board 2015 Summer Study on Autonomy

The technology of autonomy is rapidly advancing and finding widespread private sector and public sector application. Relevant capabilities span the spectrum from autonomy, i.e. the brains, to autonomous systems (e.g. robots, drones, etc.) which integrate autonomy into physical systems. Applications include IBM's Watson, the use of robotics and automation in ports and mines, autonomous vehicles (from UAVs to Google's self-driving car), automated logistics and supply chain management, and many more.

The purpose of this study is to identify the science, engineering, and policy problems that must be solved to permit greater operational use of autonomy across all warfighting domains. The study will assess opportunities for DoD to enhance mission efficiency, shrink life-cycle costs, and reduce loss of life through the use of autonomy. Emphasis will be given to exploration of the bounds—both technological and social—that limit the use of autonomy across a wide range of military operations. The study will ask questions such as: What activities cannot today be performed autonomously? When is human intervention required? What limits the use of autonomy? How might we overcome those limits and expand the use of autonomy in the near term as well as over the next 2 decades?

Applications to be considered include decision aids, planning systems, logistics, surveillance, and war-fighting capabilities. The study will also identify cost-imposing opportunities such as the use of autonomy to spoof adversaries, creating confusion and consuming their resources; and will also consider potential threats stemming from the use of autonomy by adversaries.

The study will examine the international landscape, identifying key players (both commercial and government), relevant applications, and investment trends. Considerations will include "baked-in" security, scalability, and variable cooperation between autonomous algorithms/systems and humans.

The study will consider opportunities such as: the use of large numbers of simple, low-cost (i.e. "disposable") objects vs. small numbers of complex (multi-functional) objects; use of "downloadable" functionality (e.g. apps) to repurpose basic platforms; and an ability to vary the degree of autonomy vs. human supervision/control for specific missions rather than developing mission-specific platforms.

The study will deliver a plan that identifies the barriers to increased operational use of autonomy and ways to reduce or eliminate those barriers. The study report should include: recommendations to reduce or eliminate the barrier, an assessment of risks to successful

DSB 2015 Autonomy Study: Status

- **Still awaiting release of the Report…**
- **But we can infer some conclusions from DepSecDef (Mr. Work) from his comments at last December's CNAS Inaugural National Security Forum**

*Third Offset Building Blocks**

- **Autonomous deep learning systems**
  - **Coherence out of chaos: Analyzes overhead constellation data to queue human analysts (National Geospatial Agency)**
- **Human-machine collaboration**
  - **F-35 helmet portrayal of 360 degrees on heads up display**
- **Assisted human operations**
  - **Wearable electronics, heads-up displays, exoskeletons**
- **Human-machine combat teaming**
  - **Army's Apache and Gray Eagle UAV, and Navy's P-8 aircraft and Triton UAV**
- **Network-enabled semi-autonomous weapons**
  - **Air Force's Small Diameter Bomb (SDB)**

*Keynote by Defense Deputy Secretary Robert Work at the CNAS Inaugural National Security Forum, December 14, 2015

A Spectrum of Autonomous Solutions*

Autonomy

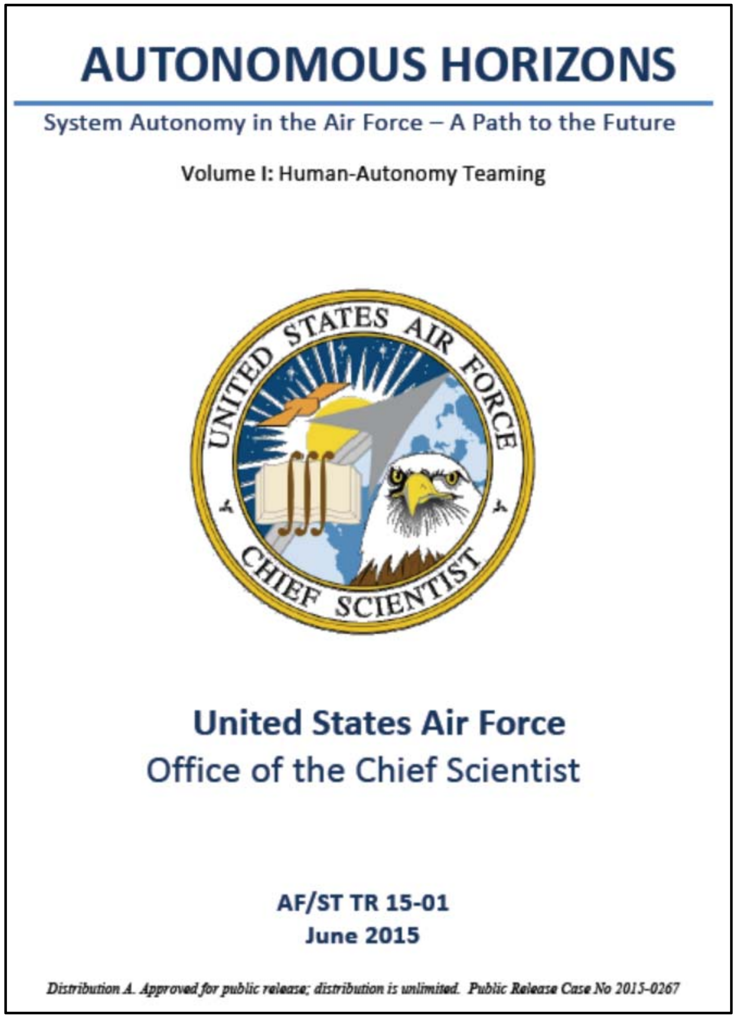
- **Assisted/enhanced human performance**
  - **Wearable electronics, heads-up displays, exoskeletons**
  - **711th HPW enhanced sensory/cognitive/motor architecture**
- **Human-machine collaboration (decision-aiding)**
  - **Humans teaming with autonomous systems**
  - **Cyborg Chess; Pilot's Associate; F-35 Helmet**
- **Human-machine collaboration (combat teaming)**
  - **Humans teaming with autonomous platforms**
  - **AFSOC Tactical Off-board Sensing Advanced Technology Demonstration (ATD)**
- **Network-enabled semi-autonomous weapons**
  - **AF's Small Diameter Bomb (SDB) for GPS-denied operation**
- **Autonomous "deep learning" systems**
  - **Autonomous systems that learn over time and "big data"; tactical learning, emergent behavior, …**
  - **AFRL's Autonomous Defensive Cyber Operations (ADCO)**

711th Human Performance Wing BATMAN project

Altius UAV Demo

* Based on Keynote by Defense Deputy Secretary Robert Work at the CNAS Inaugural National Security Forum, December 14, 2015

Autonomous Horizons I: System Autonomy in the Air Force


AUTONOMOUS HORIZONS

System Autonomy in the Air Force – A Path to the Future

Volume I: Human-Autonomy Teaming

United States Air Force
Office of the Chief Scientist

AF/ST TR 15-01
June 2015

Distribution A. Approved for public release; distribution is unlimited. Public Release Case No 2015-0267

- **Provides direction and guidance on opportunities and challenges for the development of autonomous systems for AF ops**
- **Summarizes challenges of automation and autonomy for airman interaction**
- **Calls for autonomous systems to be designed as a part of a collaborative team with airmen**
- **Highlights critical need for sufficient robustness, span of control, ease of interaction, and automation transparency**

Many Benefits of Autonomy, But Teaming is Critical

- **Main benefits of autonomous capabilities are to extend and complement human performance, not necessarily provide a direct replacement of humans**
  - **Extend human reach (eg, operate in more risky areas)**
  - **Operate more quickly (eg, react to cyber attacks)**
  - **Permit delegation of functions and manpower reduction (eg, information fusion, intelligent information flow, assistance in planning/replanning)**
  - **Provide operations with denied or degraded comms links**
  - **Expand into new *types* of operations (eg, swarms)**
  - **Synchronize activities of platforms, software, and operators over wider scopes and ranges (eg, manned-unmanned aircraft teaming)**
- **But synergistic human/autonomy teaming is critical to success**
  - **Coordination and collaboration on functions**
  - **Overseeing what each is doing and intervening when needed**
  - **Reacting to truly novel situations**

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- Background and context
- **Challenges to overcome**
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Lessons Learned from Automation

- **Traditional approaches to automation lead to "out-of-the-loop" errors (low mission SA)**
  - **Loss of situation awareness of the mission**
    - **Passive- instead of active-processing**
    - **Reduced vigilance because of complacency**
  - **Slow to detect/diagnose mission-specific anomalies/deviations**
- **Previous systems have led to poor understanding of the system's behavior and actions (low system SA)**
  - **System complexity, interface design, training**
  - **Raft of "mode awareness" incidents in commercial aviation after flight management systems (FMS) introduced**
- **Automation can actually increase operator workload and/or time required for decision-making**
- **Trust can have profound impact on system usage**

Trust in Autonomous Systems

- **Autonomous decisions can lead to high-regret actions, especially in uncertain environments → Trust is critical if these systems are to be used**
  - Current commercial applications tend to be in mostly benign environments, accomplishing well understood, safe, and repetitive tasks. Risk is low.
  - Some DoD activity, such as force application, will occur in complex, unpredictable, and contested environments. Risk is high.
- **Barriers to trust in autonomy include those normally associated with human-human trust, such as low levels of:**
  - Competence, dependability, integrity, predictability, timeliness, and uncertainty reduction
- **But there are additional barriers associated with human-machine trust:**
  - Lack of analogical "thinking" by the machine (eg, neural networks)
  - Low transparency and traceability; system can't explain its own decisions
  - Lack of self-awareness by the system (system health), or environmental awareness
  - Low mutual understanding of common goals, working as teammates
  - Non-natural language interfaces (verbal, facial expressions, body language, …)

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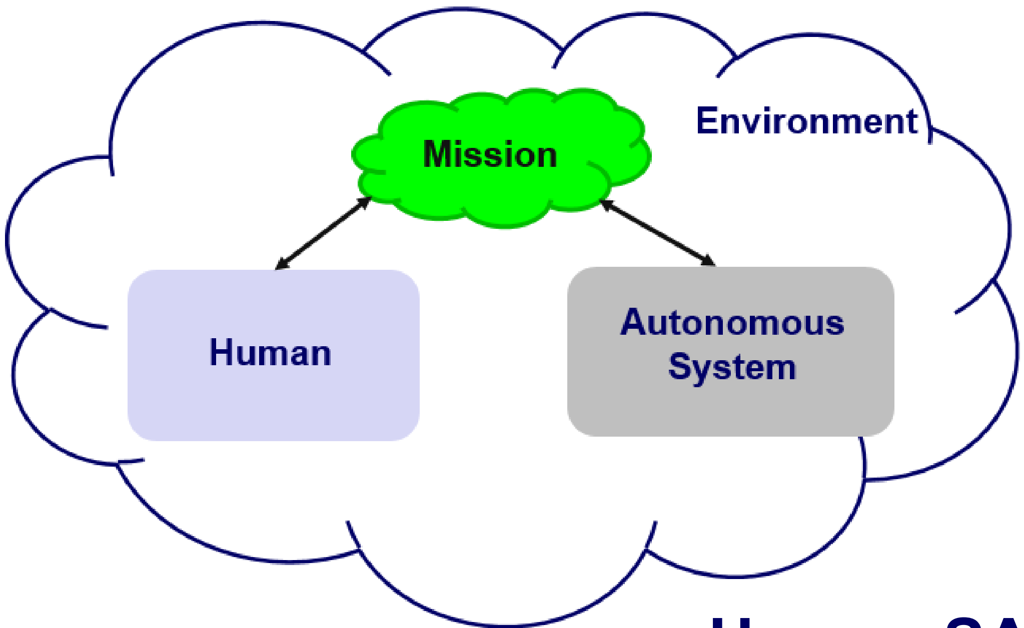
SA is Critical to Autonomy Oversight and Interaction



- **Human SA of**
  - Environment
  - Mission
  - Self
  - System
- **System SA of**
  - Environment
  - Mission
  - Self
  - Human

SA Levels and their Components

Perception

Human

- Data validity
- Automation Status
- Task Assignments
- Task Status
- Current Goals

Autonomy

- Data validity
- Human Status
- Task Assignments
- Task Status
- Current Goals

Comprehension

Human

- Impact of Tasks on Autonomy Tasks
- Impact of Tasks on System/Environment
- Impact of Tasks on Goals
- Ability to Perform Assigned Tasks

Autonomy

- Impact of Tasks on Human Tasks
- Impact of Tasks on System/Environment
- Impact of Tasks on Goals
- Ability to Perform Assigned Tasks

Projection

Human

- Strategies/Plans
- Projected actions

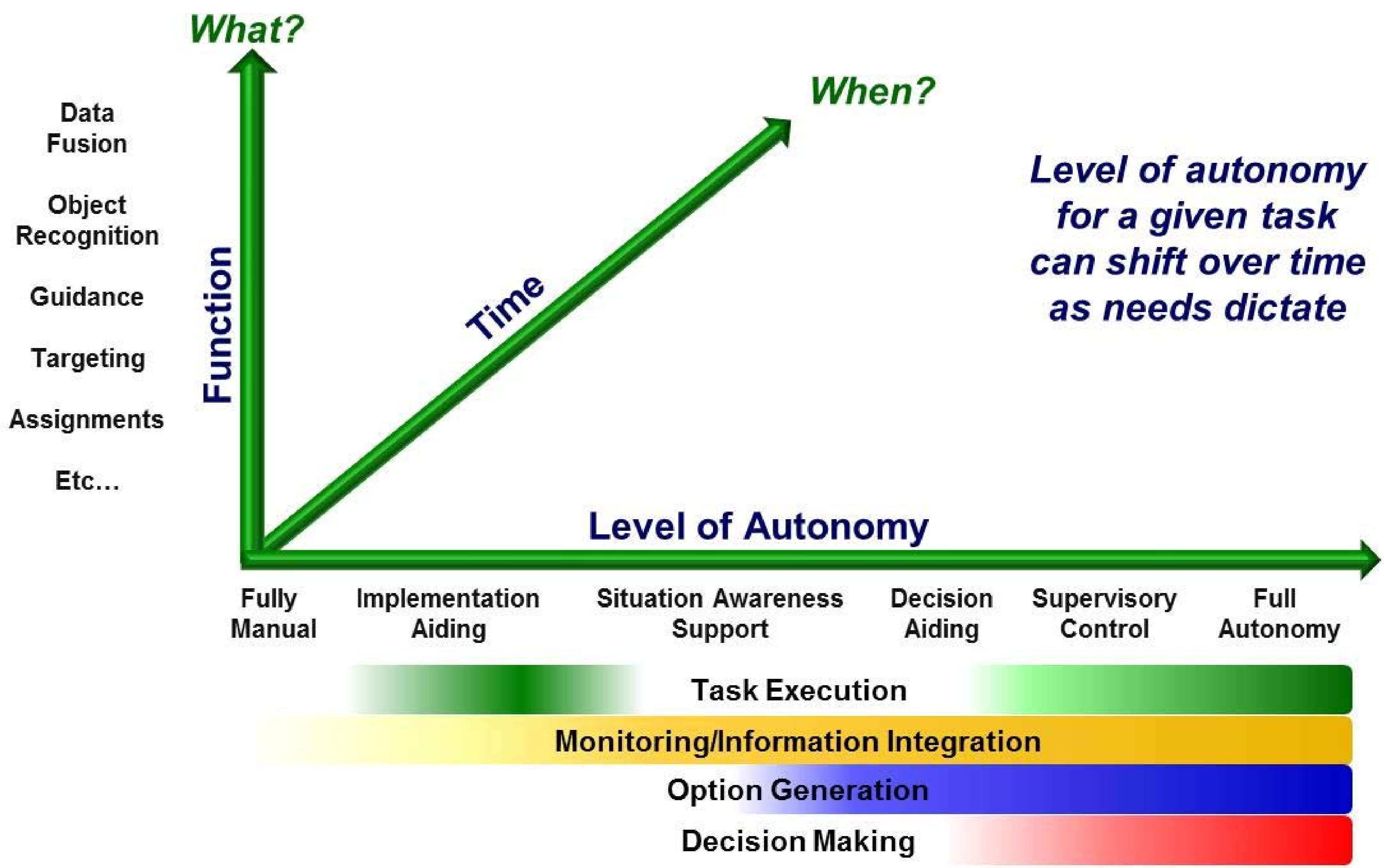
Autonomy

- Strategies/Plans
- Projected actions

Reducing Workload and Reaction Time, and Improving Performance

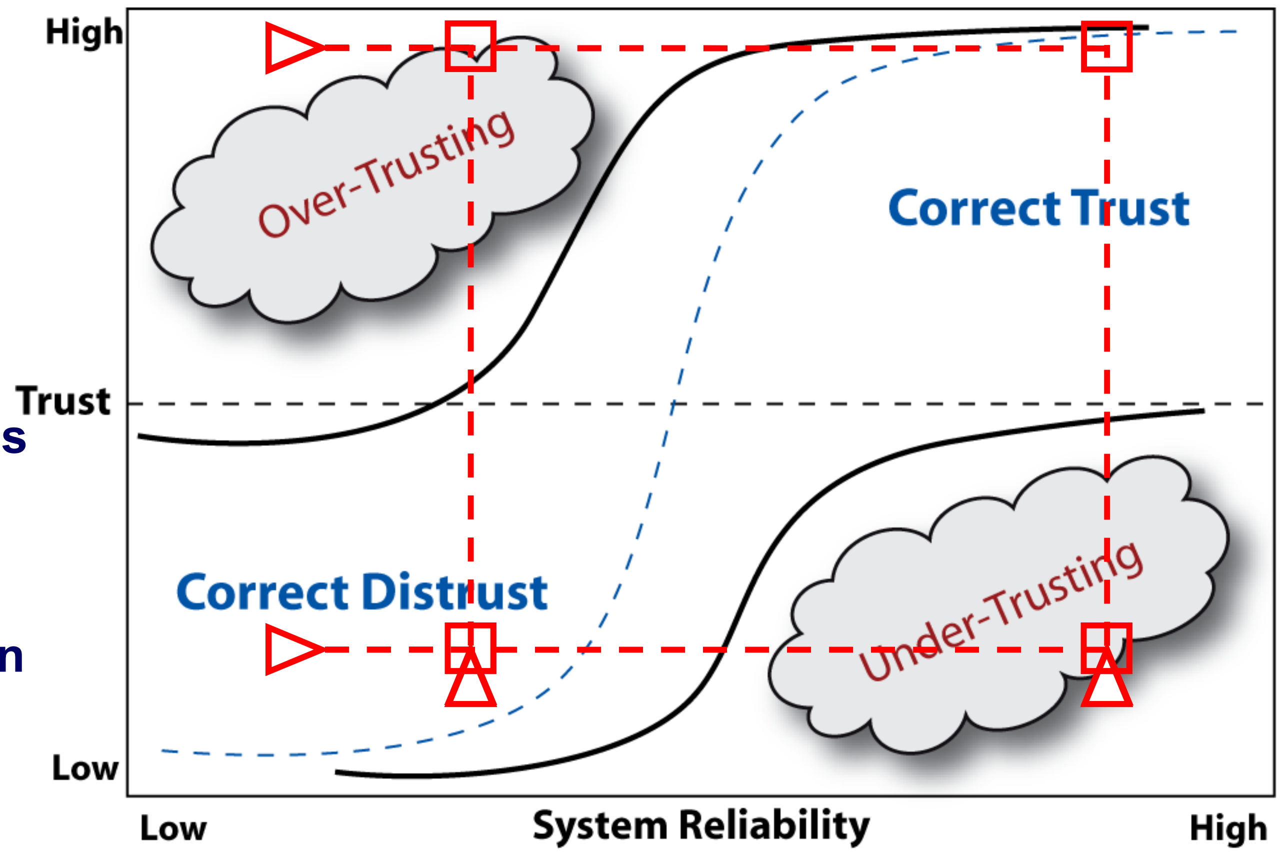
- **Supervised, flexible autonomy**
  - **Human in ultimate control: Can oversee, modify behavior as needed**
  - **Autonomy levels available that can shift over time as needed**
- **Benefits of autonomy depend on where applied**
  - **Significant benefits from autonomy that transfers, integrates, and transforms information to that needed (Level 1 and Level 2 SA)**
  - **But filtering can bias attention, deprive projection (Level 3 SA)**
  - **Significant benefit from autonomy that carries out tasks**
  - **Performance can be degraded by autonomy that simply generates options/strategies**
- **Flexible autonomy: Ability to switch tasking from human to automation and back over time and changes in mission tasks**
  - **Provides maximum aiding with advantages of human**
  - **Must be supported through the interface**
  - **Keep humans in the loop**

Flexible Autonomy



Trust: Over, Under, and Just Right

- Simple model showing partitioned trust/reliability space*
- Can use to explore transitions in trust and reliability over time
- But trust depends on many other factors
- And trust, in turn, drives other system-related behaviors, particularly usage by the operator
- But there's more we can do in the way of design and training…



*Kelley et al, 2003

Ways to Improve Human Trust of Autonomous Systems (1 of 2)

- **Cognitive congruence or analogical thinking**
  - **Architect the system at the high level to be congruent with the way humans parse the problem**
  - **If possible, develop aiding/automation knowledge management processes along lines of the way humans solve problem**
  - **Example is convergence of Endsley's SA model with the JDL fusion model**
- **Transparency and traceability**
  - **Explanation or chaining engines**
  - **If the system can't explain its reasoning, then the human teammate should be able to drill down and trace it**
  - **Context overviews and visualizations at different levels of resolution**
  - **Reducing transparency by making systems too "human-like" has the *added* problem of over-attribution of capability by the human user/teammate**
    - **Visually, via life-like avatars, facial expressions, hand gestures, ...**
    - **Glib conversational interface (eg, Eliza)**

Ways to Improve Human Trust of Autonomous Systems (2 of 2)

- **"Self-consciousness" of system health/integrity**
  - **Metainformation on the system data/information/knowledge**
  - **Health management subsystems should monitor the comms channels, knowledge bases, and applications (business rules, algorithms, …)***
  - **Need to go far beyond simple database integrity checking and think in terms of consistency checkers at more abstract levels, analogs to flight management health monitoring systems, …**
- **Mixed initiative training**
  - **Extensive human-system team training, for nominal and compromised behavior**
  - **To understand common team objectives, separate roles and how they co-depend**
  - **To develop mutual mental models of each other, based on expectations for competence, dependability, predictability, timeliness, uncertainty reduction, …**

*Yes, it's turtles all the way down

Improving Human Trust of Autonomous Systems

- **Or, more simply…**

- ***"Never trust anything that can think for itself if you can't see where it keeps its brain."***

  - **Mr. Weasley to Ginny in J. K. Rowling's, *Harry Potter and The Chamber of Secrets, 1999***

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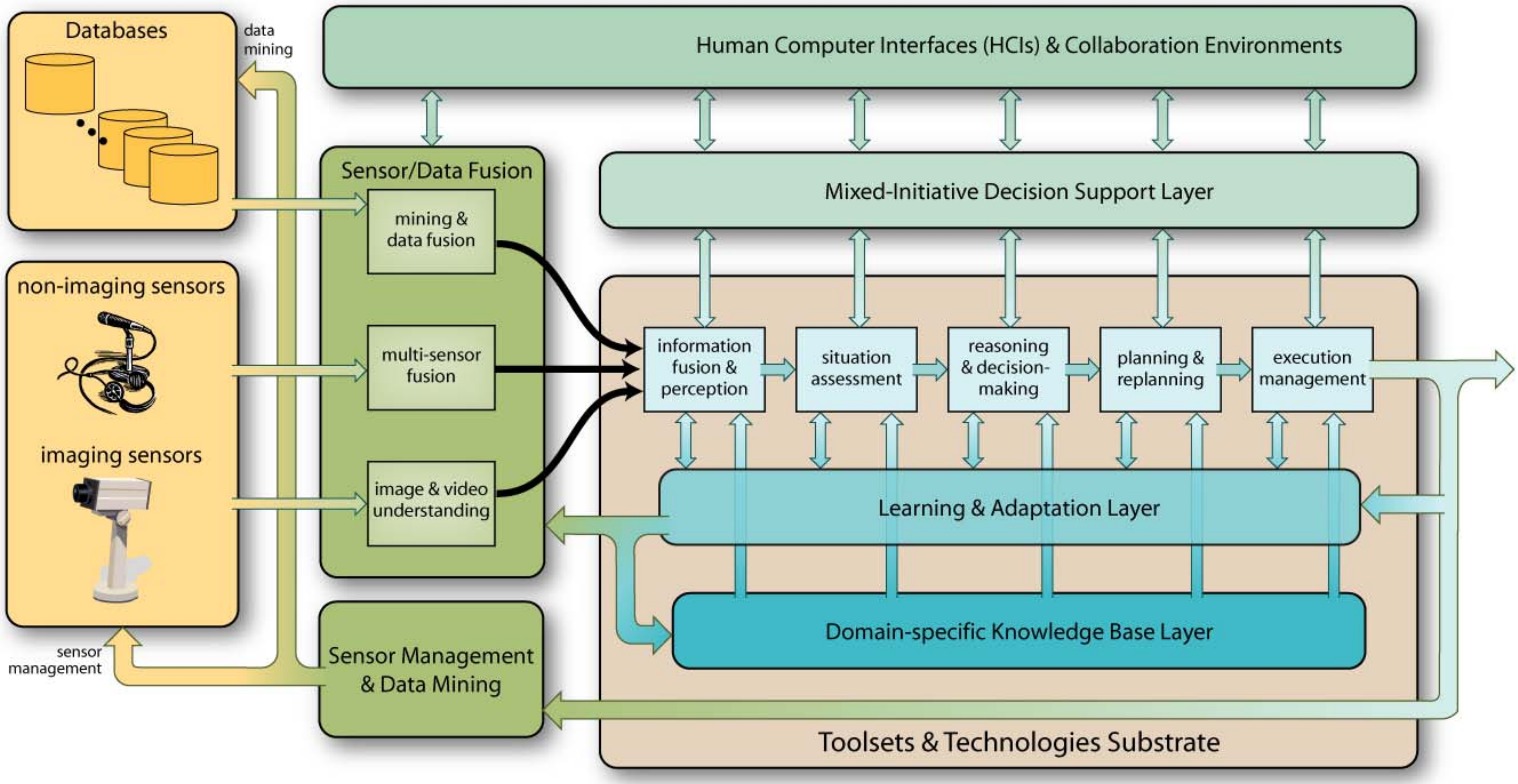
Four Tracks Towards Autonomous Systems (1 of 2)

- **Cybernetics**
  - **1940's: *The scientific study of control and communications in the animal and the machine* (Norbert Weiner)**
  - **50's – 70's: Manual control (eg, flight simulators)**
  - **70's – 90's: Supervisory control (eg, FMS)**
  - **90's – present: Cognitive models with a systems bent (e.g., COGNET, SAMPLE)**
- **Symbolic Logic ("hard" AI)**
  - **50's: Turing Test, "Artificial Intelligence" Dartmouth Symposium, General Problem Solver (Newell and Simon)**
  - **60's – 80's: Symbolic/linguistic focus, expert systems, logic programming, planning and scheduling**
  - **80's – present: Cognitive models with a logic bent (eg, Soar)**

Four Tracks Towards Autonomous Systems (2 of 2)

- **Computational Intelligence ("soft" AI)**
  - **40's: Artificial Neural Networks (ANNs)**
  - **50's: ANNs with Learning (Turing again, Hinton, LeCun)**
  - **60's – present: Genetic/Evolutionary Algorithms (Holland, Fogel)**
  - **60's – 90's: Fuzzy Logic (Zadeh)**
  - **80's – present: Deep Learning**
    - ***We've ceased to be the lunatic fringe. We're now the lunatic core.*** **(Hinton)**
    - **Merging architectures for Big Data and Deep Learning, to influence cognitive architectures**
- **Robotics**
  - **~1900's: Remote control of torpedoes, airplanes**
  - **30's – present: "Open loop" in-place industrial robots**
  - **40's – 70's: Early locomoting robots**
  - **70's – present: "Thinking" locomoting robotics**
    - **Actionist approach (eg, Brooks' iRobot, Google Cars, …)**
    - **Sensor-driven mental models of "outside" world; drive to "cognition"**

Potential Framework for Autonomous Systems R&D



Next Steps for AF/ST and AFRL

- **Autonomous Horizons Volume II**
  - **Focus on developing a framework that will reach across communities working autonomy issues**
    - **Identify high payoff AF autonomous systems applications**
    - **Identify technical interest groups working these problems, via Autonomy COI, others**
  - **Specify key "under the hood" functions included in that framework (eg, planning)**
  - **Evaluate key technologies that can support implementation of these functions (eg, optimization)**
  - **Lay out a research strategy and demonstration program**
- **Autonomous Horizons Volume III**
  - **Focus on critical implementation issues, including: cyber security, communications vulnerability, V&V**

AFRL Roadmap for Autonomy

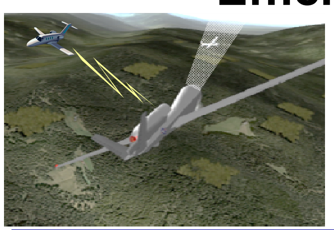
<u>Autonomy S&T Challenges</u>
Artificial Intelligence
Cognitive & Computer Science
Data Analytics
Machine & Human Learning
Guidance, Navigation & Control
Human Factors Engineering
Operations Research

Mission Continues thru A2/AD

Machine-Assisted Ops compressing the kill chain

Optimized platform operations delivering integrated ISR and weapon effects

Operating Safely & Efficiently



Defensive system mgr IDs threats & recommends actions

Intelligence analytic system fuses INT data & cues analyst of threats

Air Collision Avoidance

Work-centered PED cell

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