AFRL

THE AIR FORCE RESEARCH LABORATORY

LEAD | DISCOVER | DEVELOP | DELIVER

Air Force Science & Technology Issues & Opportunities Regarding High Performance Embedded Computing

23 September 2009

Dr. Richard Linderman

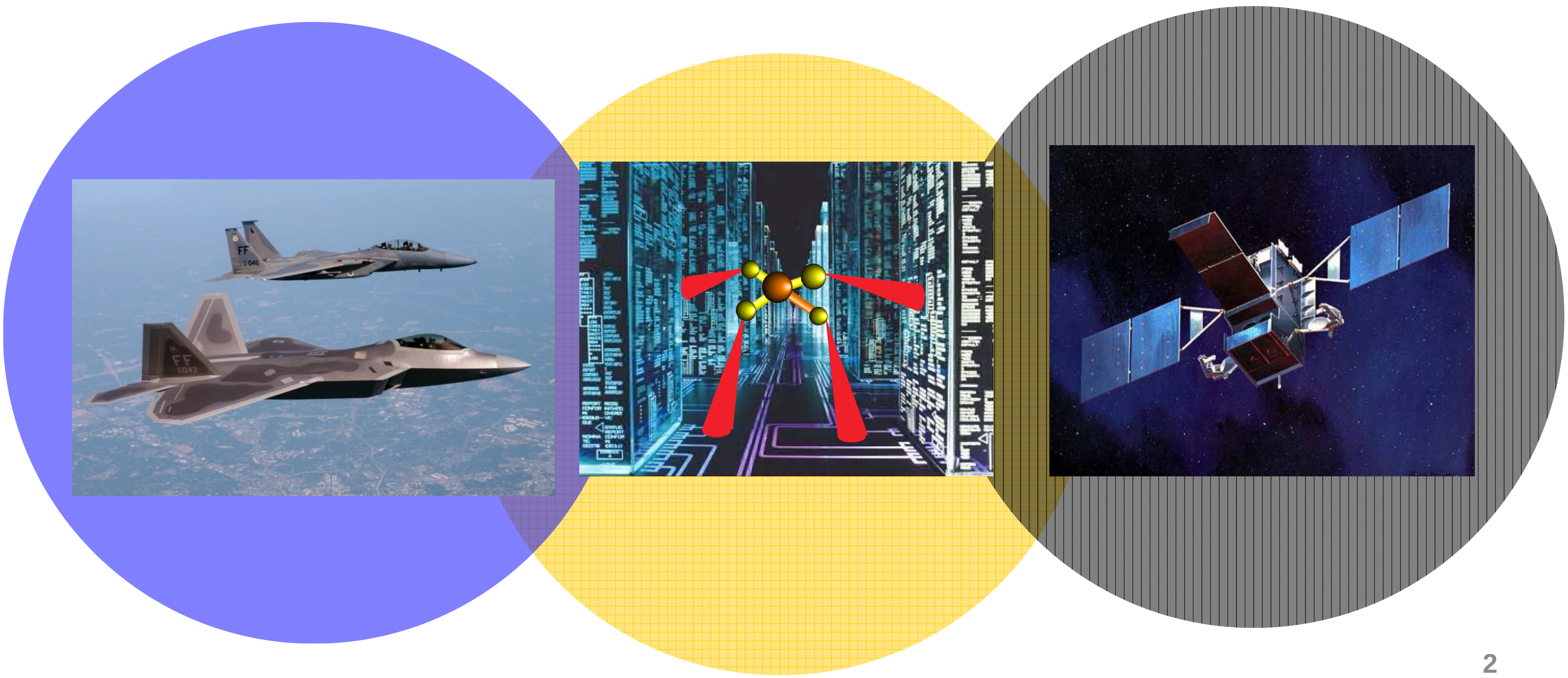
Air Force Senior Scientist for

Advanced Computing Architectures

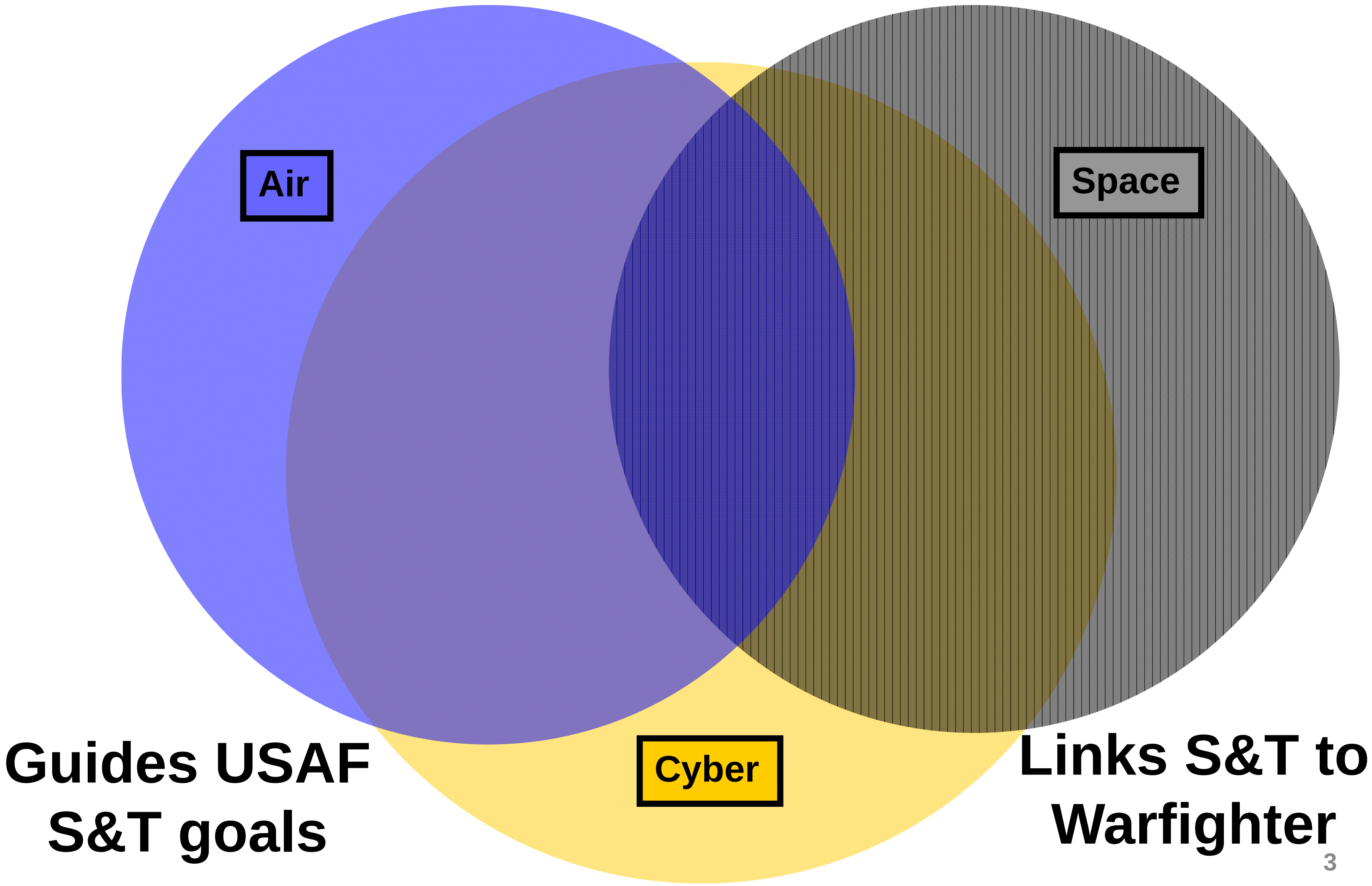
Air Force Research Laboratory

Information Directorate

The mission of the United States Air Force is to fly, fight and win… in <u>Air</u>, <u>Space</u> and <u>Cyberspace</u>.



USAF S&T Vision



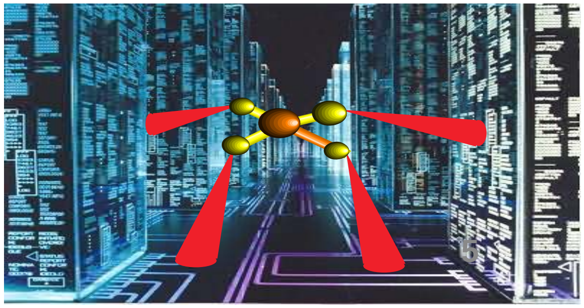
AFRL Mission

Leading **the discovery, development, and integration of affordable warfighting technologies for our air, space and cyberspace force.**

It's not just about the science…
…it's about *leadership* in S&T

Challenges by Domain

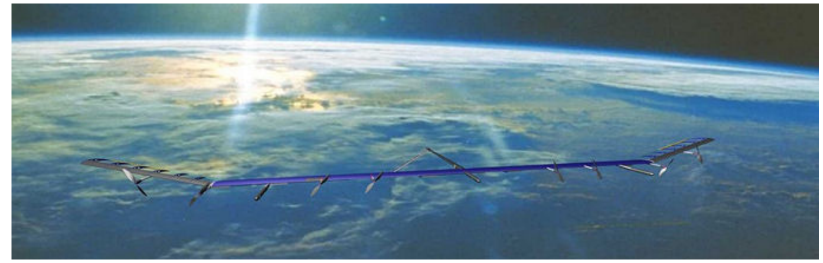
- **Air: Persistant air dominance is at risk**
  - Increasingly effective air defenses
  - Proliferation of 5th gen fighters, cheap cruise missiles, and UASs
  - Light-speed war possibilities are terrifying
- **Space: Now a contested domain**
  - Increasingly important
  - Increasingly vulnerable
- **Cyber: Cyber warfare has begun**
  - We don't control the battlespace
  - We rely on it more and more
  - We can't find the enemy

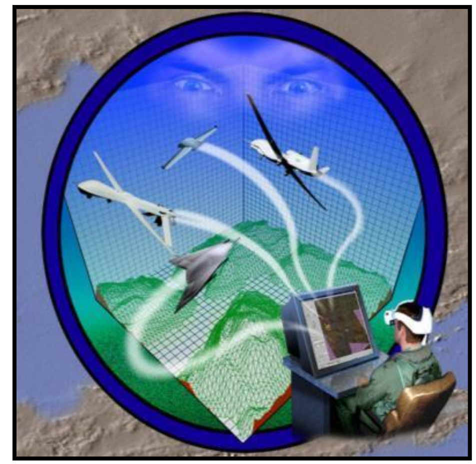


Opportunities – Air: Across the Technology Spectrum

- **Endurance** – Efficient aerodynamics, efficient propulsion, lightweight structures
- **Alternative Fuels** – Fischer-Tropsch, biomass, carbon sequestration
- **Sensors** – 360 degree coverage, structural load-bearing antennas
- **Speed** – Hypersonics, thermal, flight controls, maneuverability, payloads
- **Thermal Management** – Produce less heat, tolerate more heat, dissipate more efficiently, convert more effectively
- **Modeling & Simulation** – Virtual prototyping, live-virtual-constructive environments
- **Manufacturing Technology** – Lean, diagnostics, just-in-time production
- **UASs** – Swarming, semi-autonomous then autonomous, learning, healing
- **Micro Air Vehicles** – Sensor miniaturization, flight agility, autonomy
- **Integrated Systems Health Management** – Self-reporting systems, autonomous reconfiguration to maintain mission capability
- **Responsive** to needs of sister services, needs of the Nation

Opportunities – Air:
“We Can Control the Vertical”

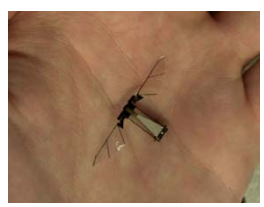


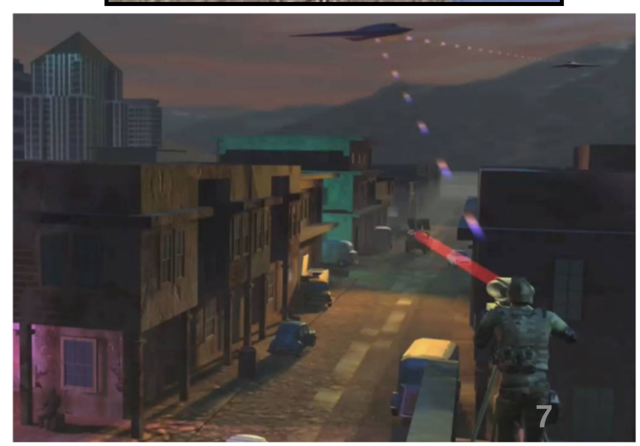


- C^2ISR (High-to-Medium Altitudes)
  - Endurance
    - Aerodynamics
    - Propulsion
  - Layered Sensing
    - Sensors
    - Processing & Integration

- ATTACK (Medium Altitudes)
  - Swarming Brains (UAVs)
    - Programming & Processing

- URBAN & SOLIC (Low Altitudes)
  - Maneuverability
    - Morphing structures, bio-mimetics
  - Miniaturization
    - Micro- & Nano-
  - Autonomy
    - Sensors
    - Game Theory & Processing



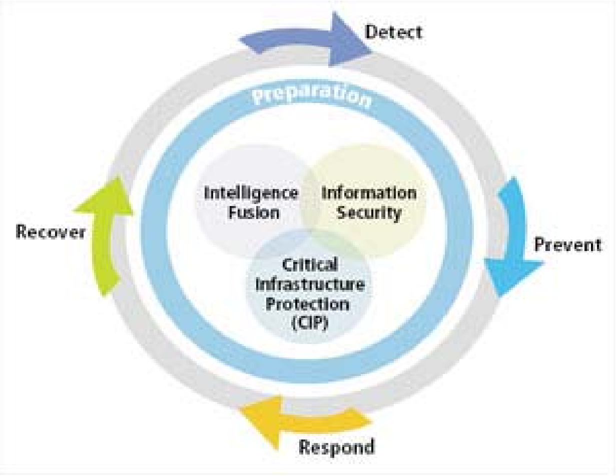


Opportunities – Space: SSA & ORS

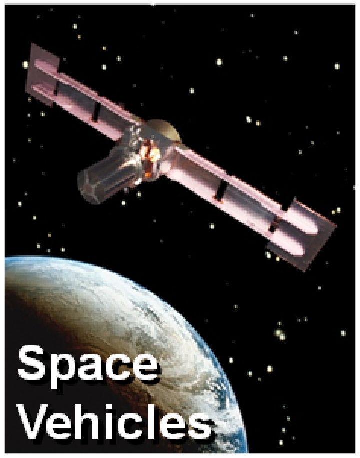
- **Space Situational Awareness**
  - High resolution imaging
  - Electro-optical phenomenology
  - Advanced astrodynamics
  - Modeling and decision aids
- **Operationally Responsive Space**
  - Plug ‘n’ Play Satellites
  - Small vs Large Satellites
  - Quick Launch
  - Fast On-Orbit Checkout

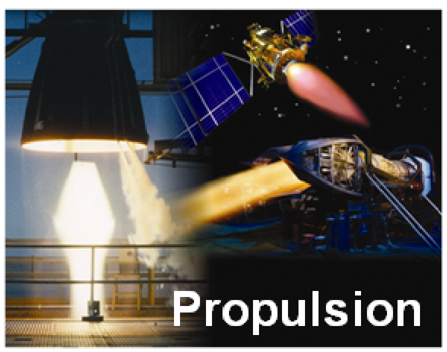
Opportunities – Cyber: Robust, Resistant, Resilient

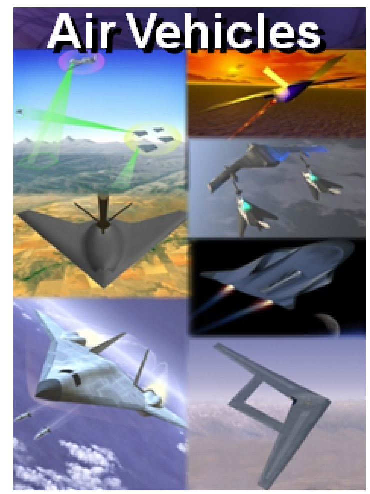
- **Must be able to take a <u>series</u> of punches, jabs, feints...and survive!**
- **"Fight <u>through</u> the Attack!"**
  - **Endure...mitigate...recover... reconstitute...get up...move forward!**
- **Move beyond "One Air Force – One Network" to "Defending the Nation"**
- **Evolve to a polymorphic system of systems that naturally favors:**
  - **Stability**
  - **Security**
  - **Cyber-Sensing**
  - **Partitionable**
  - **Rapid Reconstitution**
  - **Focus on Protecting & Delivering Data**



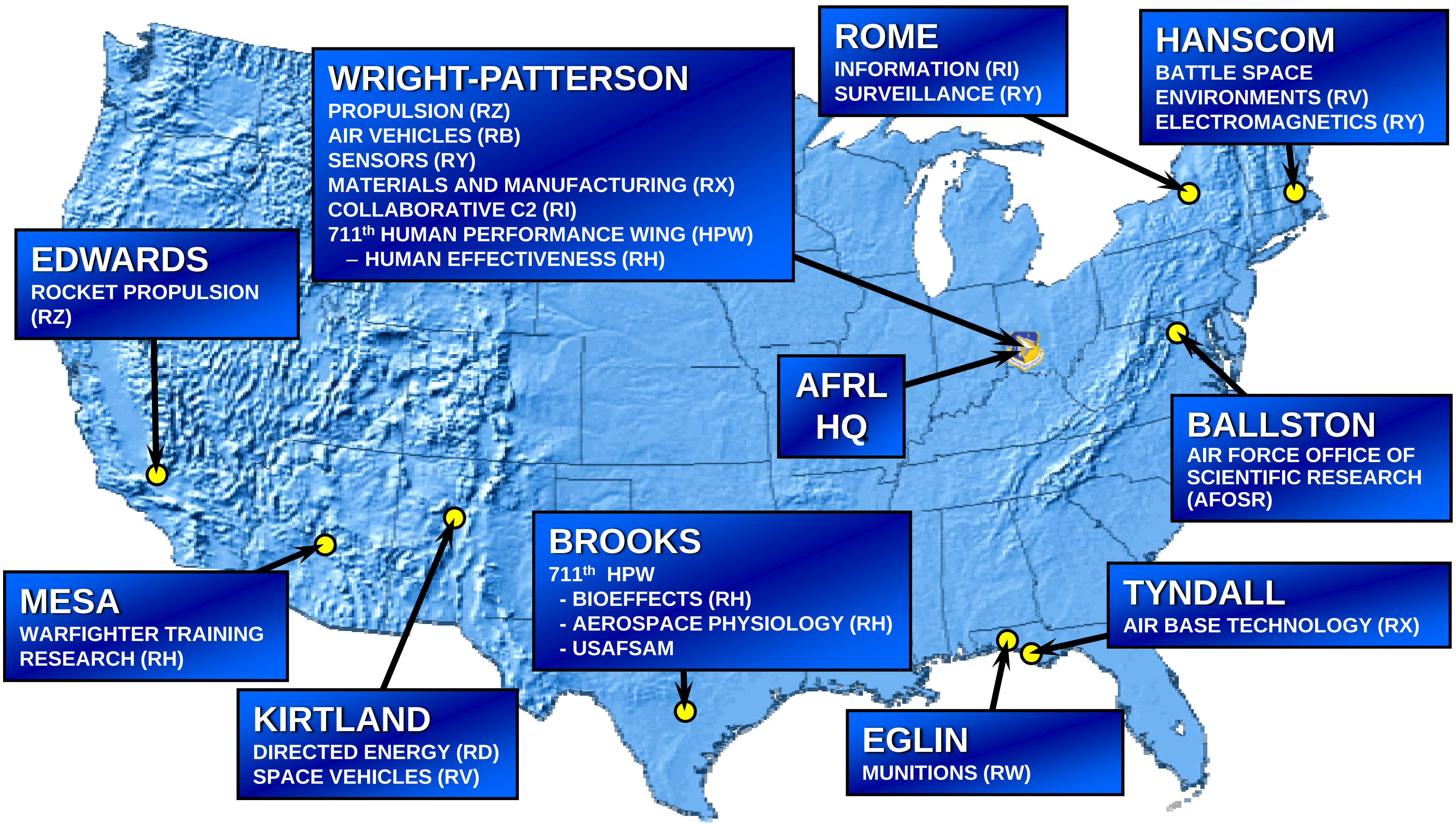
Ten Technical Directorates







Major AFRL Facilities



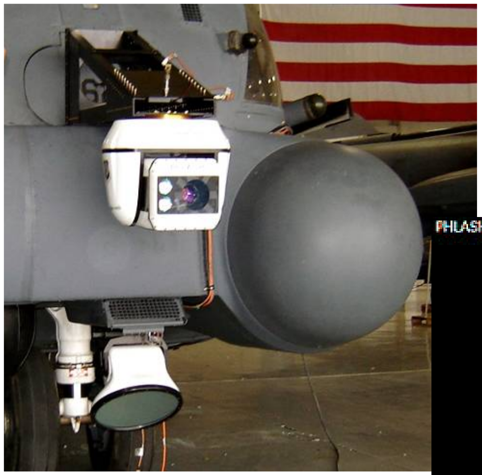
40 Sites World-Wide

Focused Long Term Challenges and Discovery

FLTC #1	Anticipatory Command, Control & Intelligence (C2I)
FLTC #2	Unprecedented Proactive Intelligence, Surveillance and Reconnaissance (ISR)
FLTC #3	Dominant Difficult Surface Target Engagement/Defeat
FLTC #4	Persistent & Responsive Precision Engagement
FLTC #5	Assured Operations in High Threat Environments
FLTC #6	Dominant Offensive Cyber Engagement
FLTC #7	On-demand Force Projection, Anywhere
FLTC #8	Affordable Mission Generation & Sustainment
Discovery	Questions the Air Force doesn't even know to ask

Rapid Reaction Solution for Brownout

PhLASH - Photographic Landing Augmentation System for Helicopters



9 months from Idea to Demo

Problem

- Helicopter landings at arid sites stir up blinding dust clouds (Brown-out)

Solution

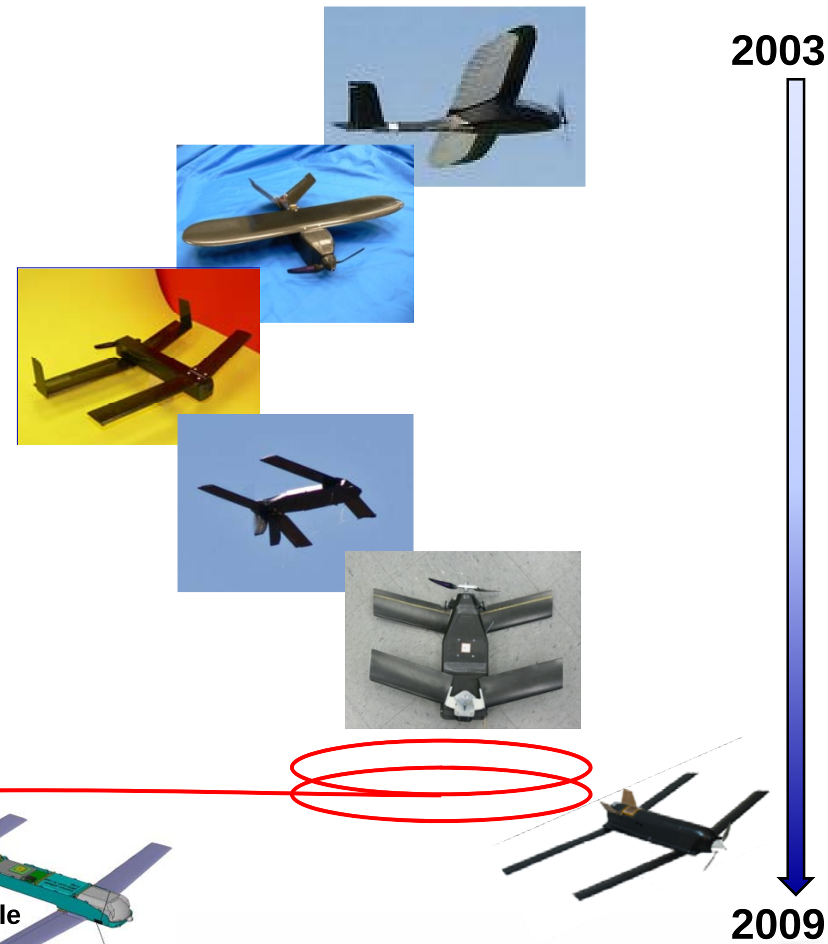
- High resolution image of the landing zone and fly into the image

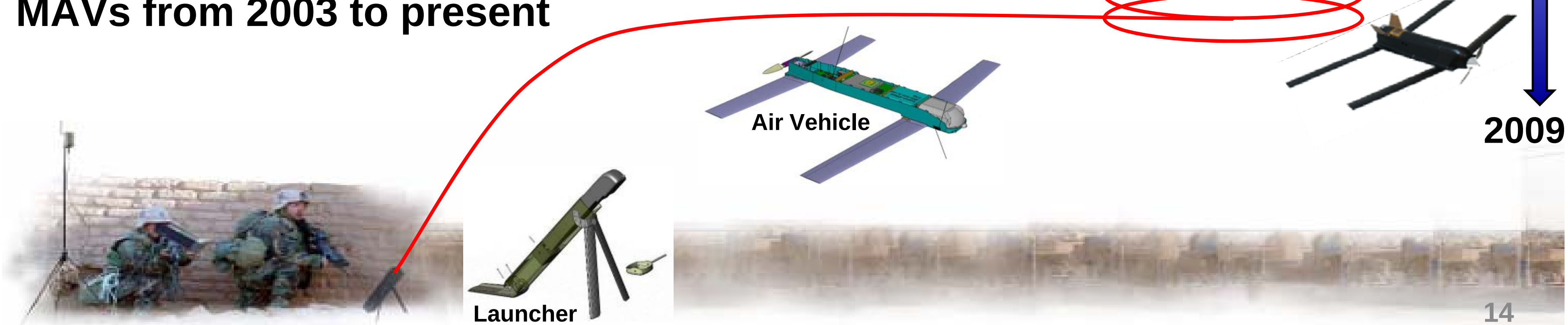
Technologies

- High Resolution Near-IR flash photography
- Advanced Image processing / reconstruction based on GPS location

Micro Air Vehicle Development

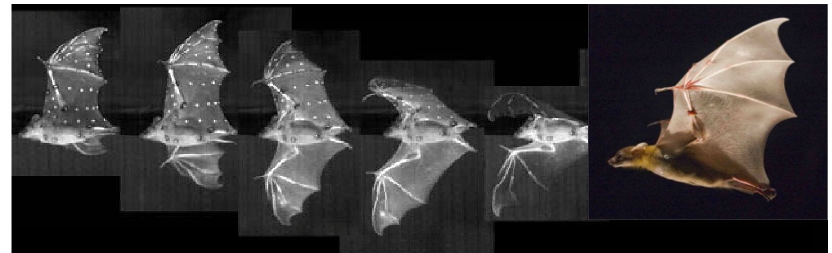
- Built many mission specific development designs
  - Bomb Damage Information sensing, chem/bio sensing, terminal guidance improvements, weaponization, and general R&D activities for both AFRL and other government agencies
- Optimized Tandem wing design
- Air launch and dismount tube launch
- Pictures show the family of AFRL MAVs from 2003 to present

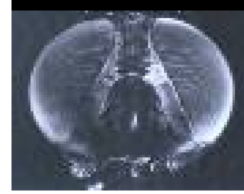


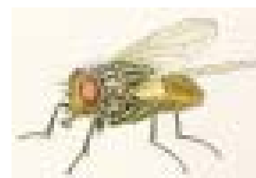


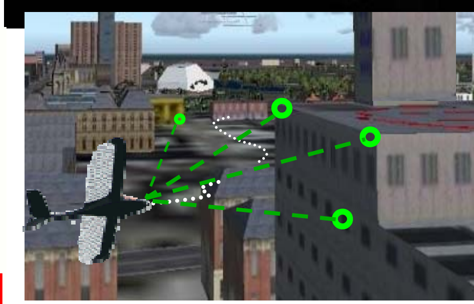
Bio-Inspired Micro Air Vehicles

- Characterize aeromechanics and scalability of bat flight
- Bat wing motion has many Degrees of Freedom, unlike insects/birds
- Highly flexible wing structure & membrane
- Arrays of raised hair sensors-actuators that may provide flow sensing & influence flight control
- Active vision control (fly eye) for imaging, tracking and guidance





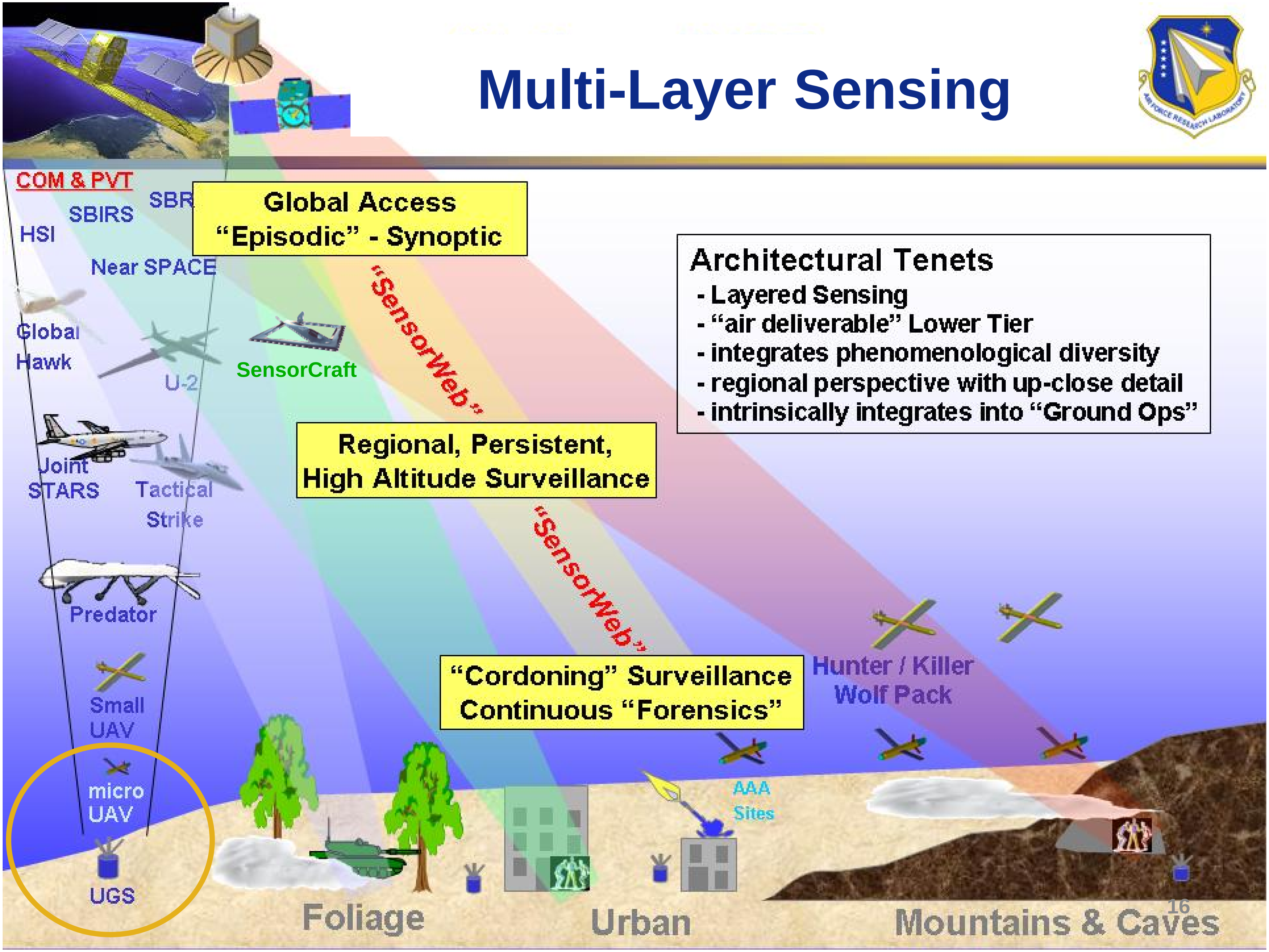




Bio-Inspired: Fly eye & Bat Flight Kinematics

2015 Goal: Bird-Sized MAV **2030 Goal: Insect-Sized MAV**

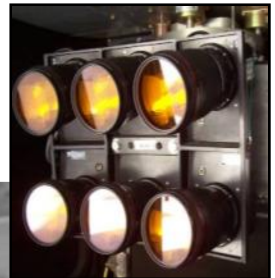
Multi-Layer Sensing



Architectural Tenets
- Layered Sensing
- "air deliverable" Lower Tier
- integrates phenomenological diversity
- regional perspective with up-close detail
- intrinsically integrates into "Ground Ops"

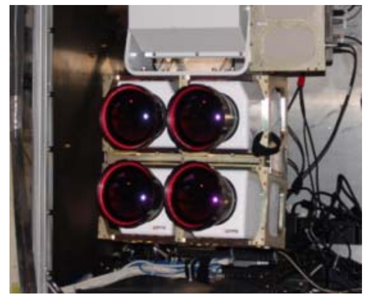
AFRL Staring Sensor Technology

Day (AngelFire)



IRAQ

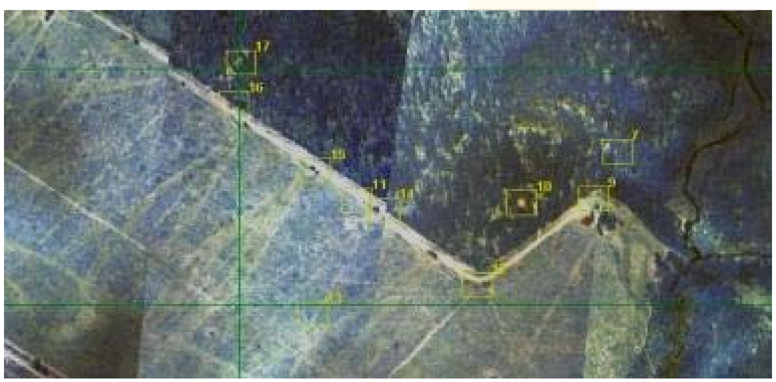
IR (Night Stare)



Area B →

Multispectral

(SPIRITT) Sensor →



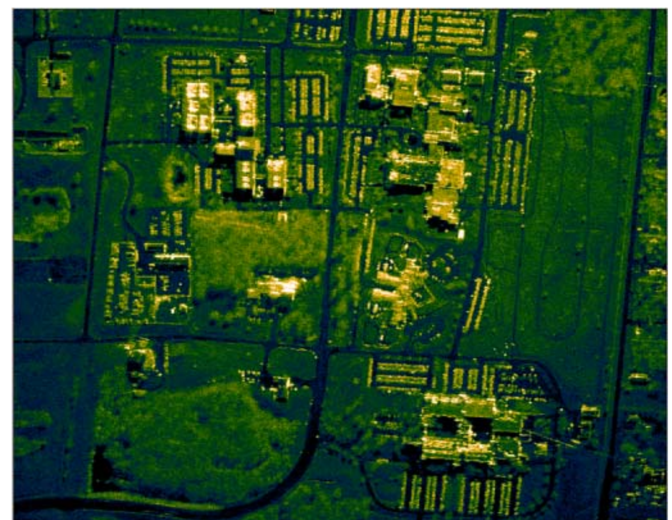
Radar

All Weather

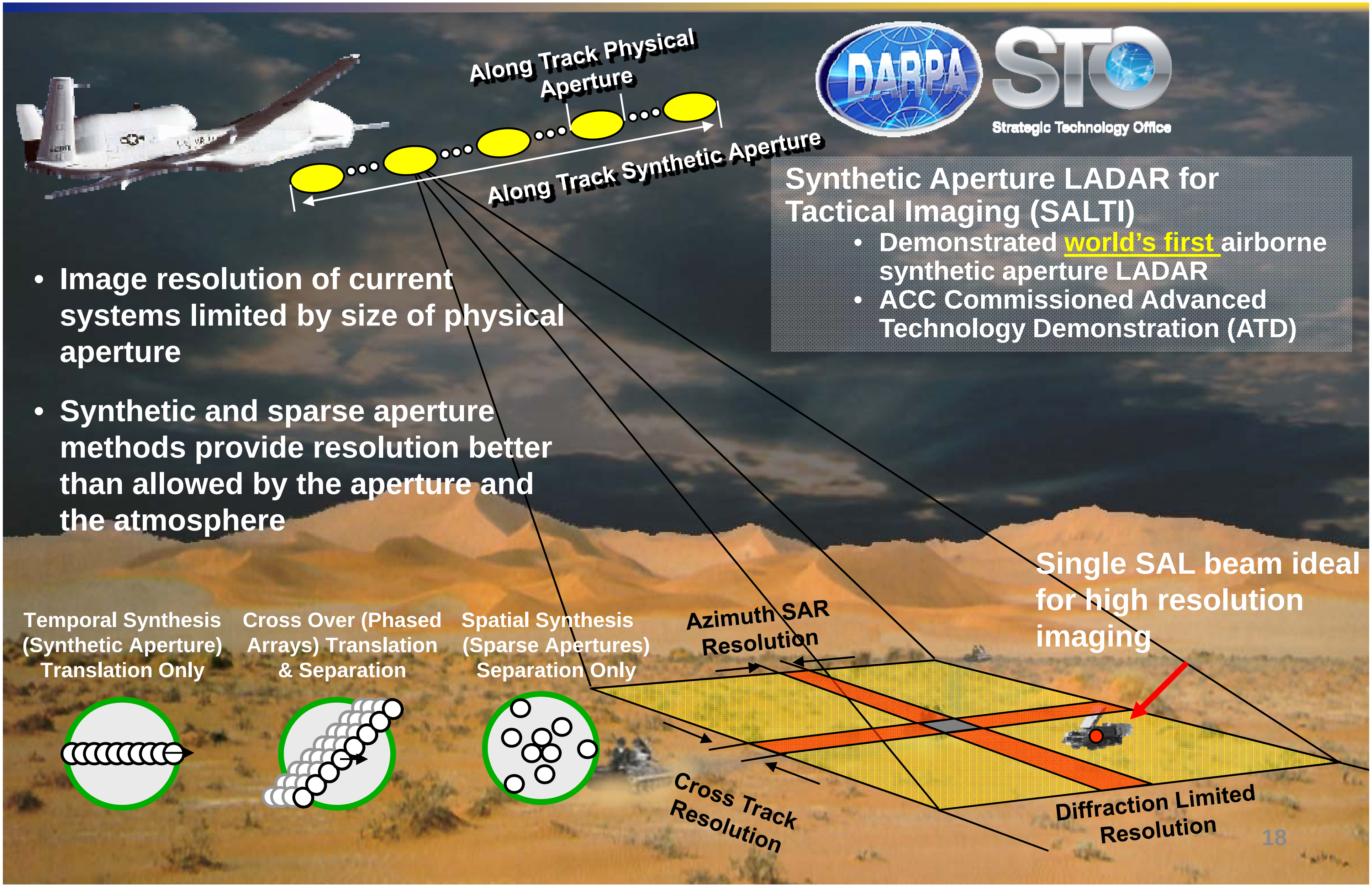
Video SAR

(Gotcha)

Area B →



Synthetic Aperture LADAR (SAL)



- Image resolution of current systems limited by size of physical aperture
- Synthetic and sparse aperture methods provide resolution better than allowed by the aperture and the atmosphere

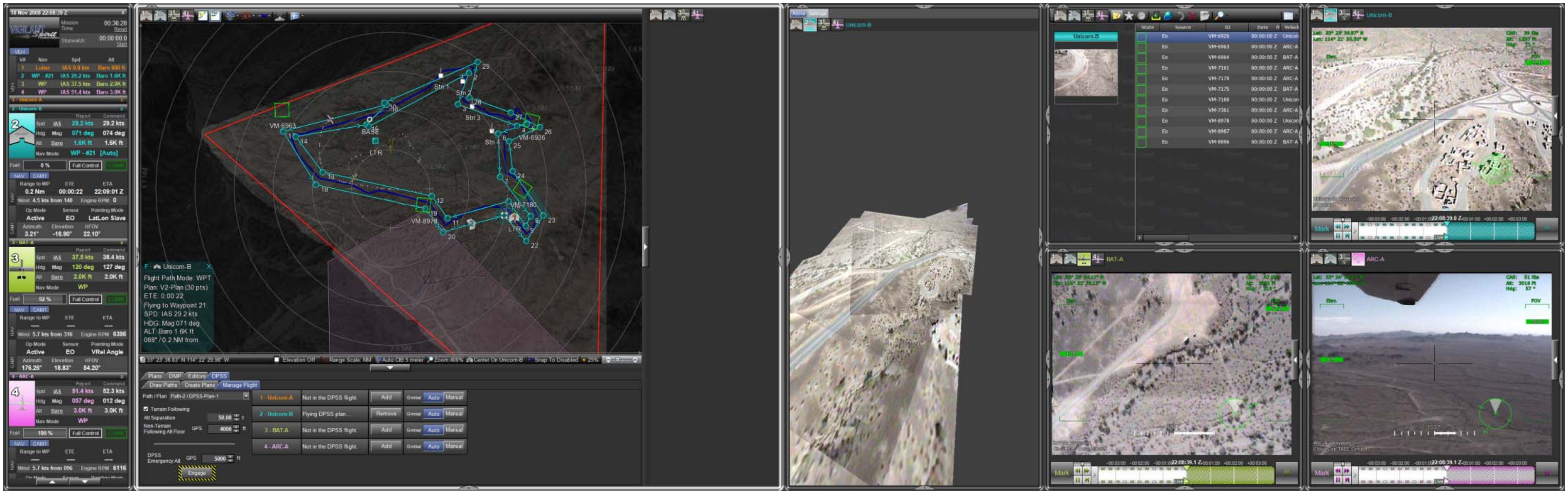
Synthetic Aperture LADAR for Tactical Imaging (SALTI)

- Demonstrated world's first airborne synthetic aperture LADAR
- ACC Commissioned Advanced Technology Demonstration (ATD)

COUNTER: Cooperative Operations in Urban Terrain

- Automated control system for multiple UASs
  - •Allocate Resources
  - •Route Vehicles
  - •Avoid no-fly zones
  - •Respond to alarms

- •Data collection interface for ISR
  - •Steer sensors
  - •Fuse Information

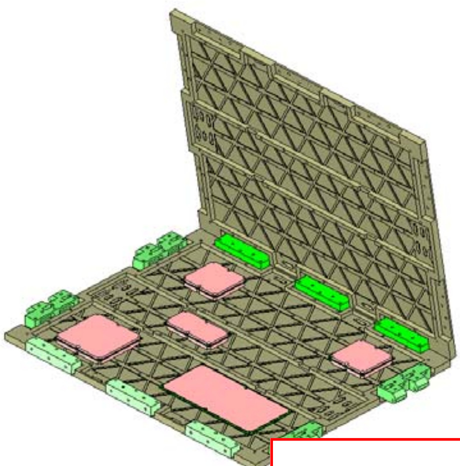


Yuma Flight Test – Nov 08

(4 Vehicles – 2 Zaggi's, 1 Bat-III, 1 Acturus T-16)

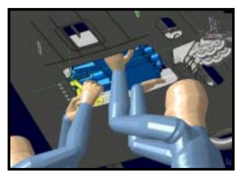
Operationally Responsive Space

- **Apply operational aircraft concepts to space systems**
  - **Tailored mission capabilities**
  - **Rapid Build-Up/Turn times**
  - **Air Tasking Order responsiveness**
  - **Satellite buses with plug-and-play payloads**
  - **Sustained high operations tempo**

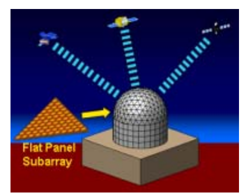


Play Video

Responsive Spacecraft

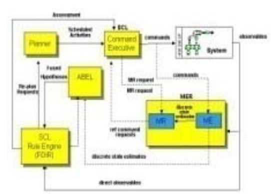


Ground Handling



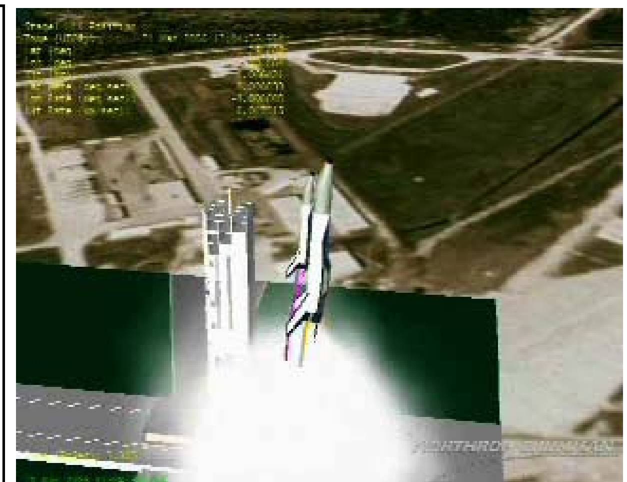
Satellite Control

On-Orbit Checkout



On-Orbit Autonomy

Responsive Operations

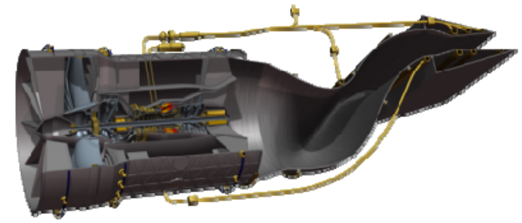


Responsive Launch

Software Defined UAV Ops Center Mock-up

Software Defined Command Center is a synthesis of hardware, software and conceptual approaches with potential application to multiple command centers in the Air Force

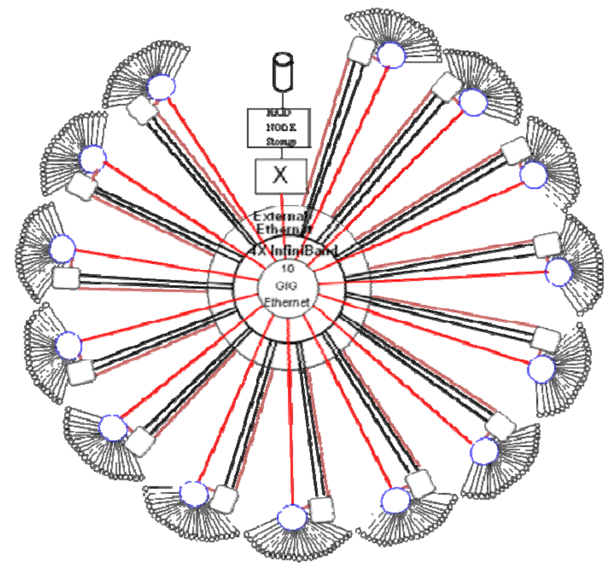
SensorCraft
Future High Altitude Long Endurance ISR Platform



Global Hawk	Next Generation System
24+ Hours of endurance	Highly fuel efficient, 40-50 hours of endurance
Single Band (X) Air to Ground sensing payload	Dual Band (UHF and X), Air to Air <u>and</u> Air to Ground sensing for small and hidden targets
Side looking	360 degree coverage
Raw data to Mission Control Element	Fused data to user
Conventional antennas, radomes	Large, embedded structural arrays
Conventional wings, 139 ft	Flexible active wings, 200+ ft

53 TFLOPSs
Cell Cluster Architecture

- The Cell Cluster has a peak performance of 51.5 Teraflops from 336 PS3s and additional 1.4 TF from the headnodes on its 14 subclusters.



- Cost: $361K ($257K from HPCMP)
  - PS3s 37% of cost

- Price Performance: 147 TFLOPS/$M

- The 24 PS3s in aggregate contain 6 GB of memory and 960 GB of disk. The dual quad-core Xeon headnodes have 32 GB of DRAM and 4 TB of disk each.

Cell Cluster: Early Access to Commodity Multicore

This project provides the HPCMP community with early access to HPC scale commodity multicore through a 336 node cluster of PS3 gaming consoles (53 TF).

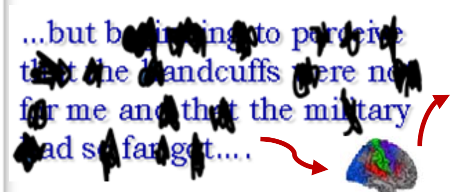
Applications leveraging the >10X price-performance advantage include:

large scale simulations of neuromorphic computing models

GOTCHA radar video SAR for wide area persistent surveillance

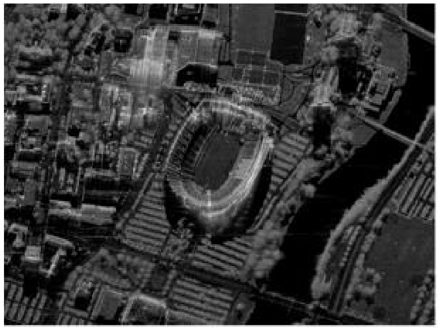
Real-time PCID image enhancement for space situational awareness

Dr. Richard Linderman, AFRL/RI, Rome, NY

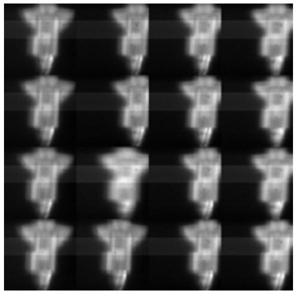


… but beginning to perceive that the handcuffs were not for me and that the military had so far got …

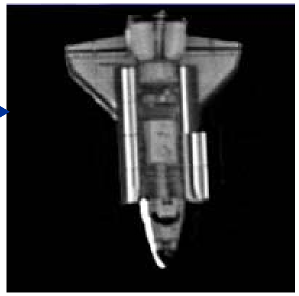
Neuromorphic example:
Robust recognition of occluded text



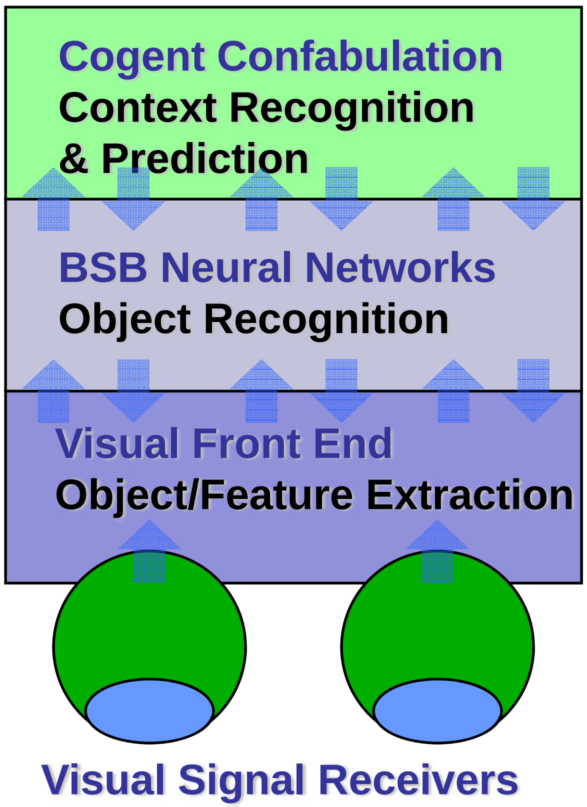
Gotcha SAR



PCID Image Enhancement



An Integrated Framework for Visual Cognition

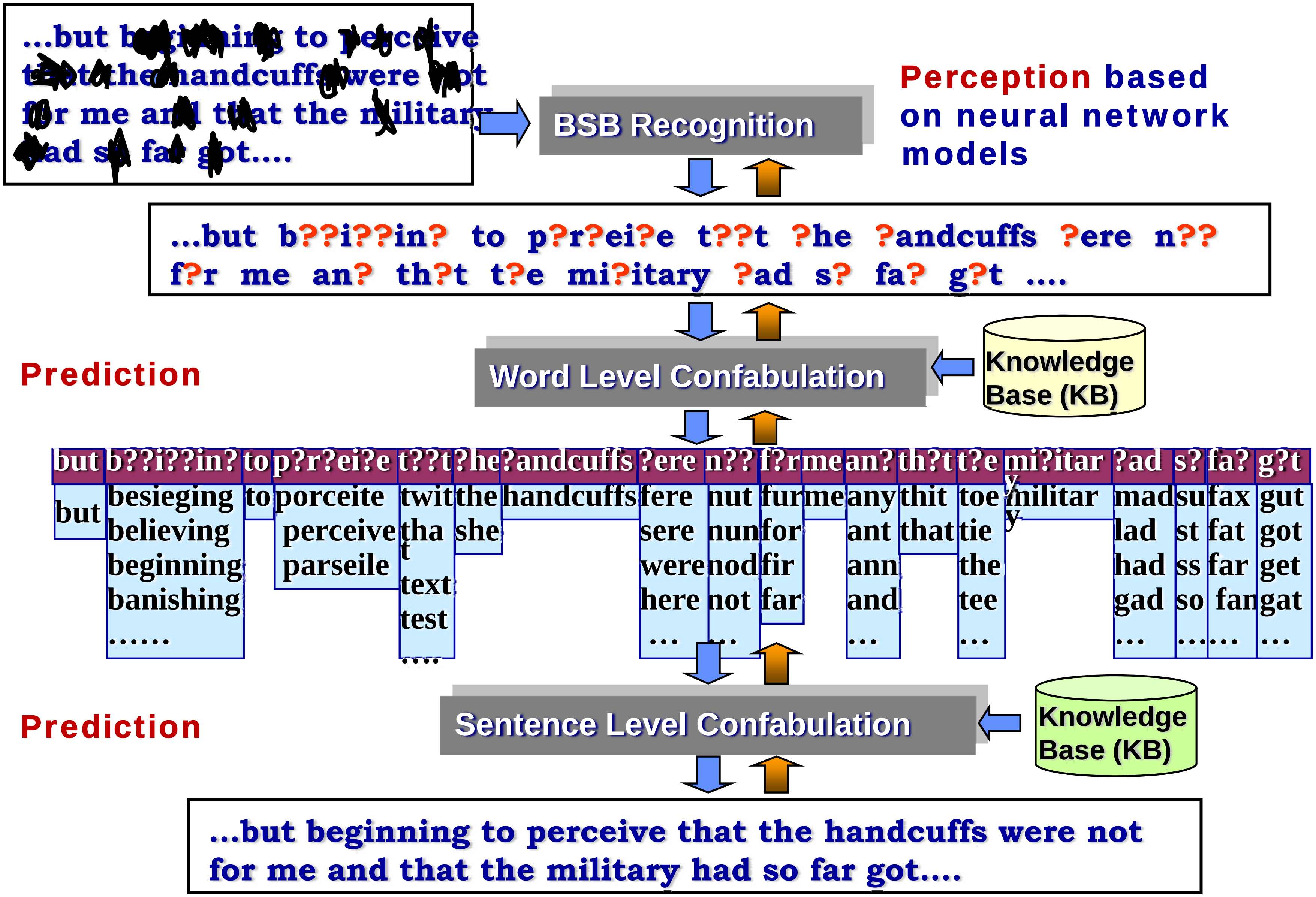


Concept-level learning, recognition and prediction

Recognition based on raw visual data

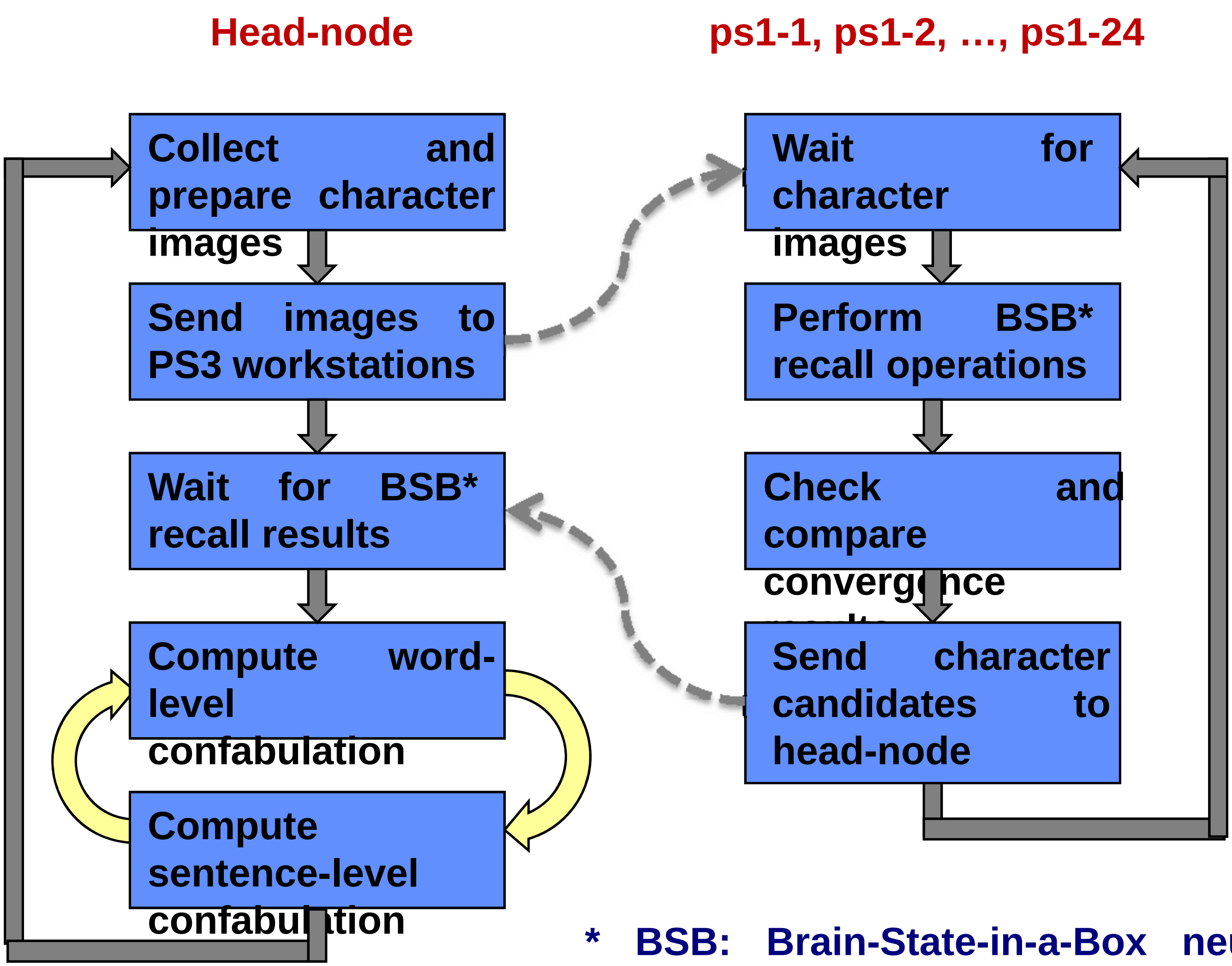
Extract important visual objects and features

Hybrid Cognitive Model for Text Recognition



Text Recognition Workflow on PS3 Cluster

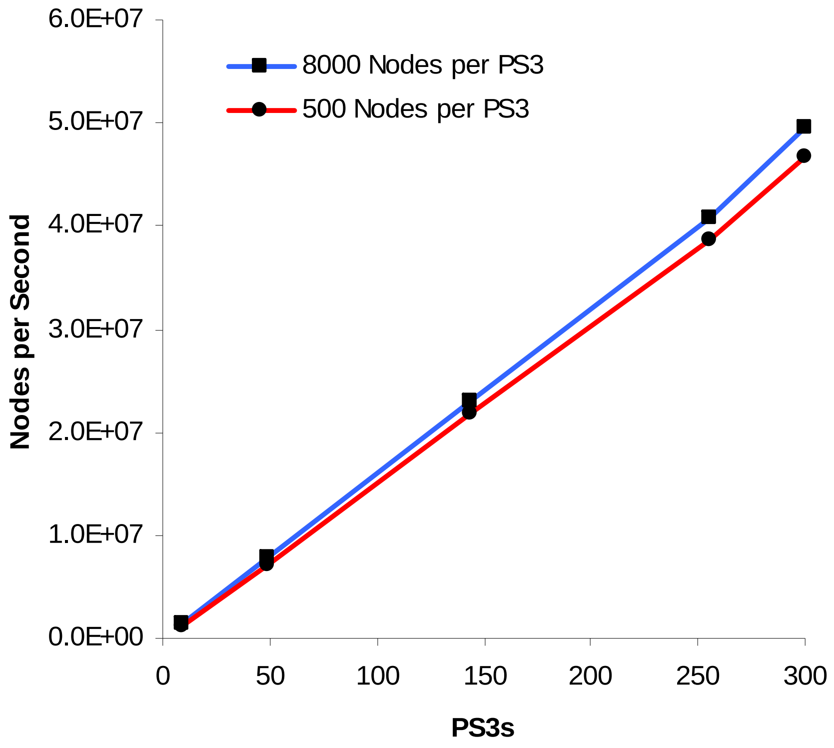
Single PS3 sub-cluster: 1 head-node + 24 Playstation3 (PS3) workstations



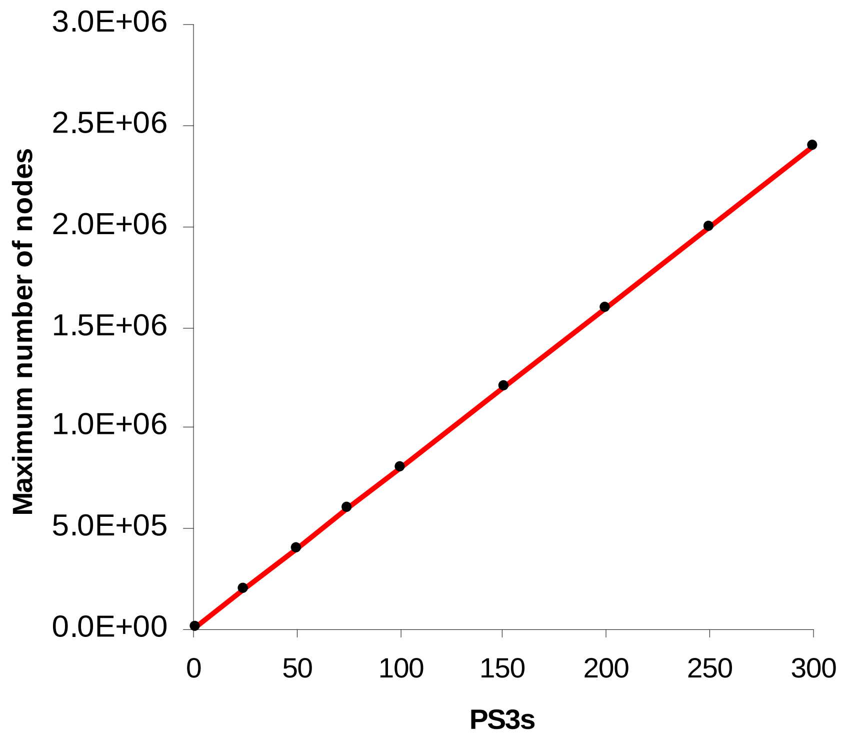
* BSB: Brain-State-in-a-Box neural network model

Scaling the Hierarchical Temporal Memory Model

Run Time Performance

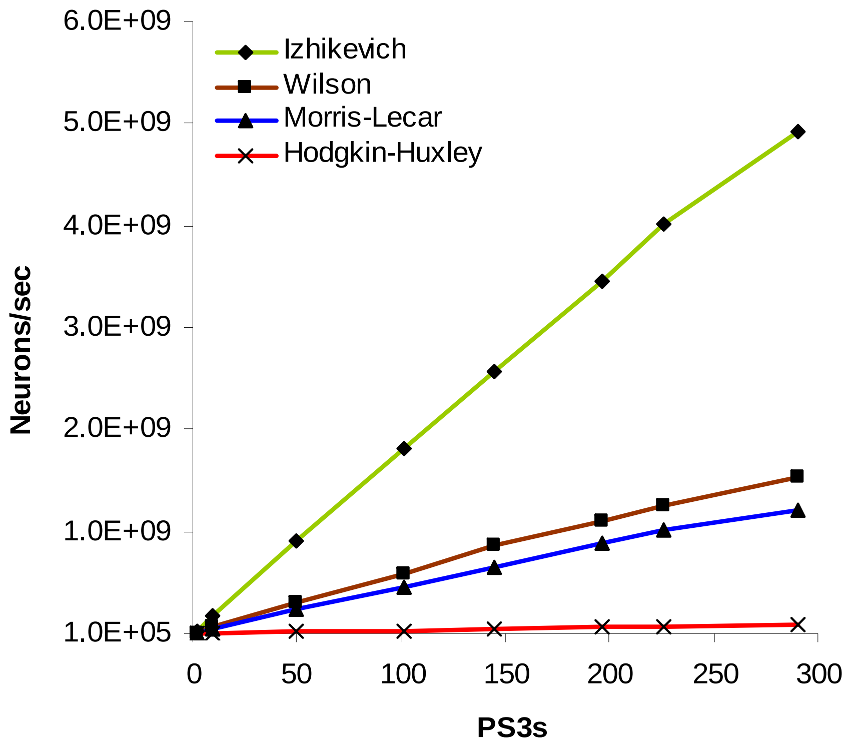


Network capability

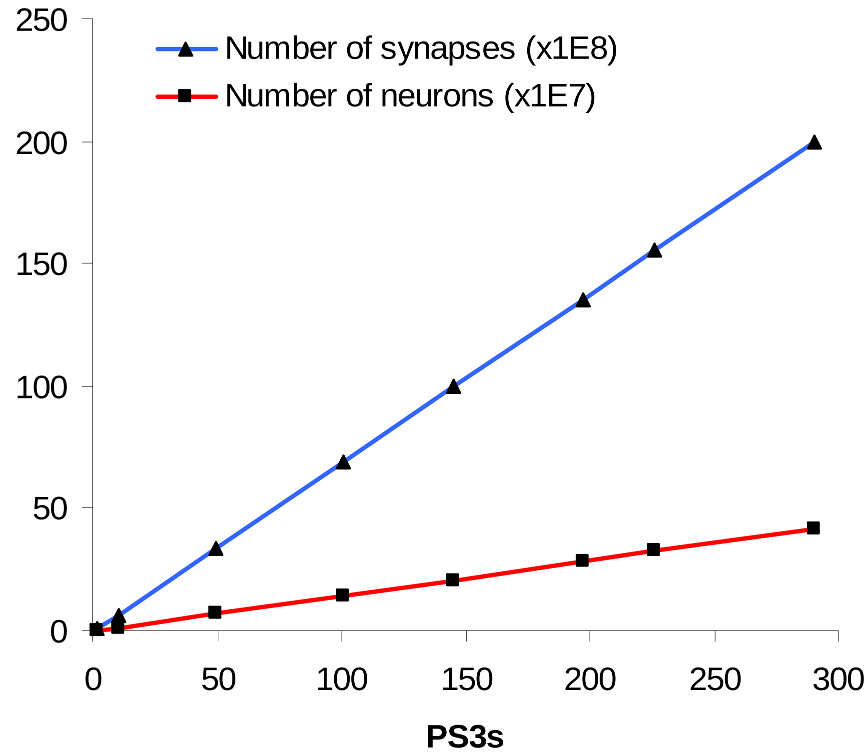


Scaling Spiking Neural Net Models

Run Time Performance

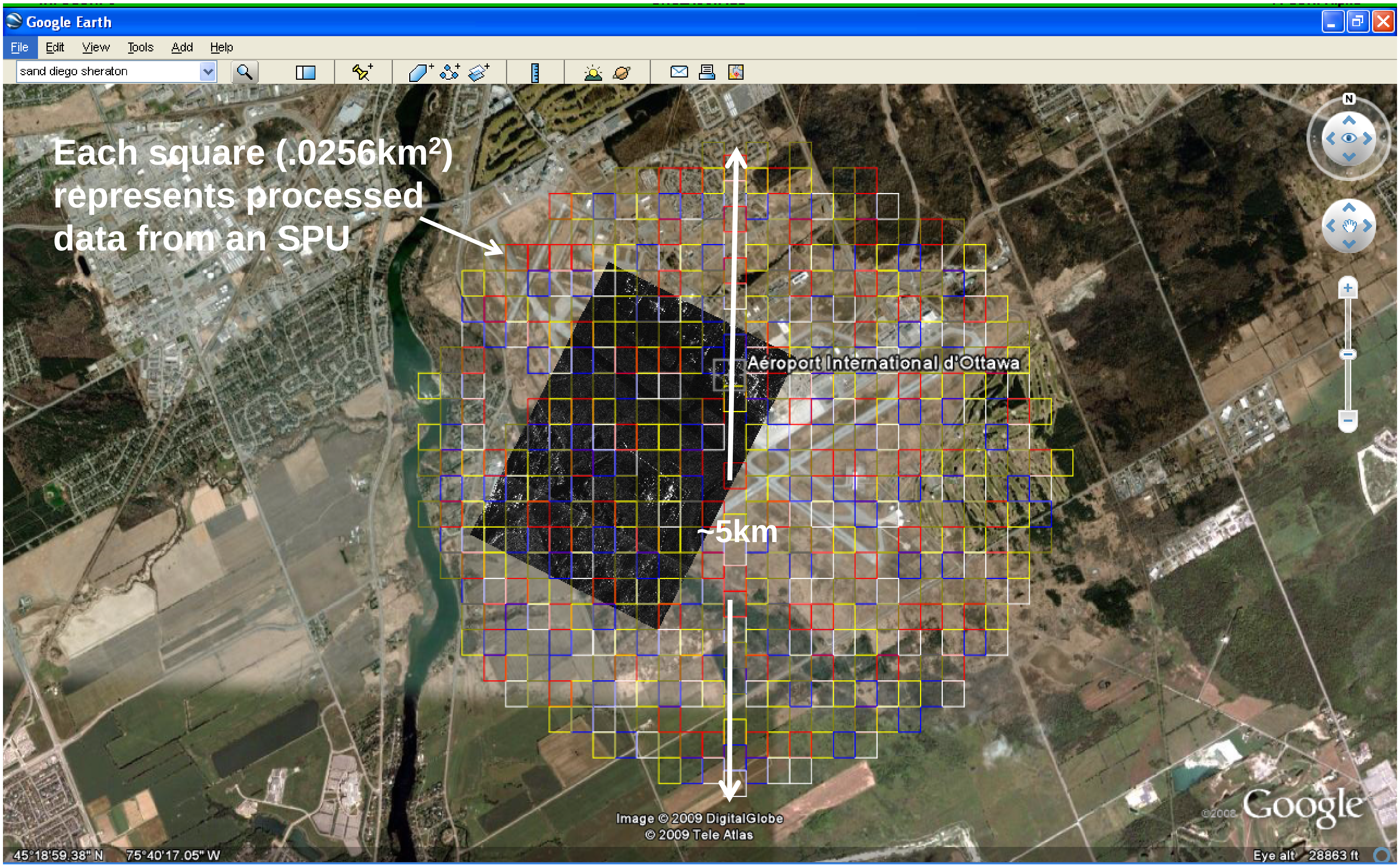


Network capability*



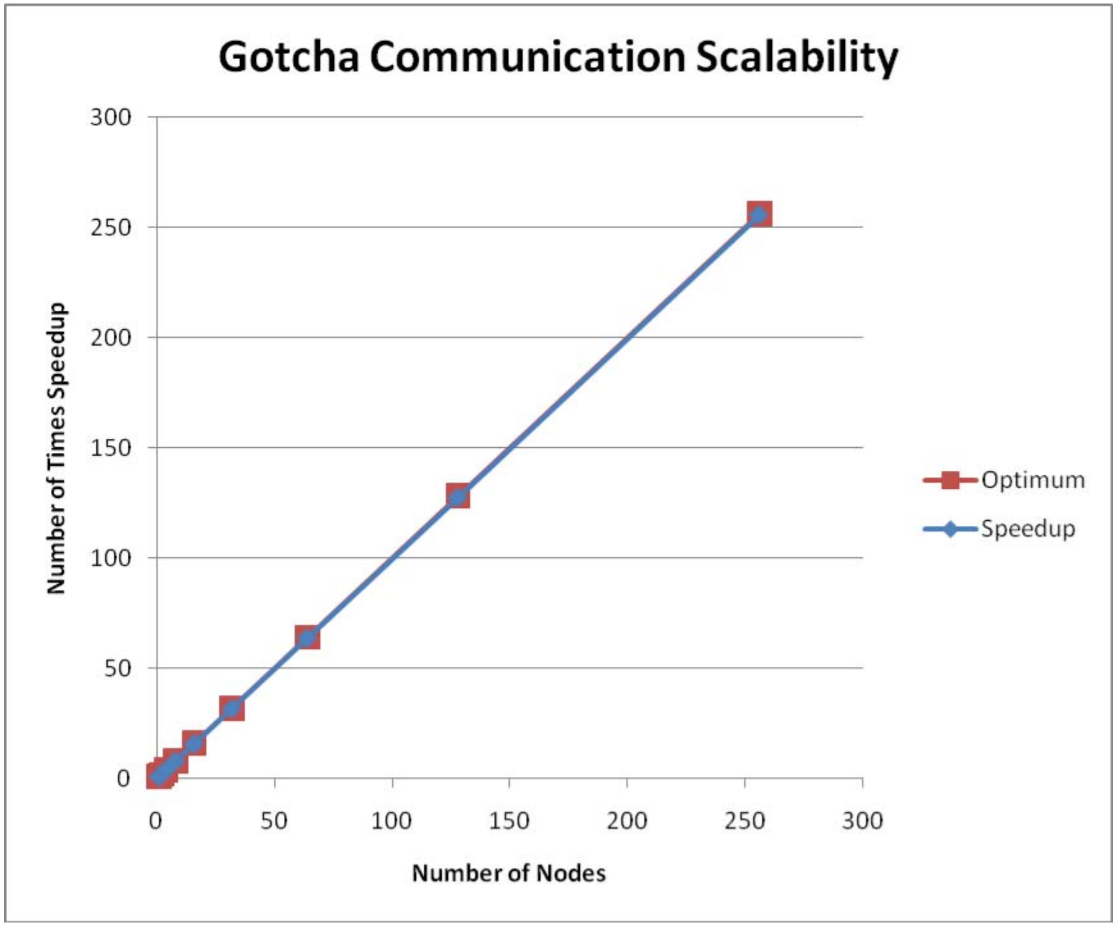
***Note that the number of neurons and synapses that could be implemented are heavily determined by the specific network structure developed. More biologically accurate models are currently being studied and are likely to yield different numbers.**

96 PS3's (576 SPU cores) processing 5km Gotcha SAR



Results: Gotcha VideoSAR Scalability

- At 256 PS3s, each send 6 MB/sec and receives 8.4 MB/sec while headnodes each receive 200 MB/sec and send 140 MB/sec



Great News for HPEC!

OFFICE OF THE DIRECTOR
DEFENSE RESEARCH AND ENGINEERING
3040 DEFENSE PENTAGON
WASHINGTON, D.C. 20301-3040

2 June 2009

MEMORANDUM FOR DEPUTY ASSISTANT SECRETARY OF THE ARMY (RESEARCH AND TECHNOLOGY)
CHIEF OF NAVAL RESEARCH
DEPUTY ASSISTANT SECRETARY OF THE AIR FORCE (SCIENCE, TECHNOLOGY AND ENGINEERING)
DIRECTOR, PROGRAM ANALYSIS AND EVALUATION
DIRECTOR, TEST AND EVALUATION AND TECHNOLOGY REQUIREMENTS, DEPARTMENT OF THE NAVY
DIRECTOR, MISSILE DEFENSE AGENCY
DIRECTOR, DEFENSE ADVANCED RESEARCH PROJECTS AGENCY
DIRECTOR, DEFENSE THREAT REDUCTION AGENCY
DIRECTOR, TEST AND EVALUATION MANAGEMENT AGENCY, DEPARTMENT OF THE ARMY
DIRECTOR, TEST AND EVALUATION DIRECTORATE, DEPARTMENT OF THE AIR FORCE

SUBJECT: FY 2010 DoD High Performance Computing Modernization Program Dedicated HPC Project Investment Awards

Reference: Office of the Director, Defense Research and Engineering Memorandum, Subject: *Call for DoD FY 2010 Dedicated High Performance Computing Project Investment (DHPI) Proposals*, December 2008

Dedicated HPC Project Investments (DHPIs) are modest-sized HPC systems that are awarded to technically sound, mission critical projects which cannot be performed at DoD Supercomputing Resource Centers (DSRCs) due to classification level, special operational requirements (e.g., real-time turnaround), and/or use of emerging technologies. DHPIs are a vital part of the DoD HPC Modernization Program's mission to address the most pressing HPC needs of the DoD S&T and T&E communities.

All proposals were subjected to rigorous independent review by the DHPI Technical Evaluation Panel (which includes HPC subject matter experts from Government, industry, and academia), the Service/Agency Principals, and the DUSD(S&T) Directors. I would like to thank the Service/Agency Principals for their careful review and refinement of this year's DHPI proposals. As a result, the process was more competitive and aligned with DoD priorities.

It is my pleasure to announce that the following DHPIs have been selected for award for FY 2010:

DHPI	Organization	Project Leader
Maui Space Surveillance System Advanced Image Reconstruction	Air Force Research Laboratory, Directed Energy Directorate (RD)	Maj. David Strong
500 Tflop/s Cluster for Real-Time Neuromorphic Computing and Gotcha Video SAR	Air Force Research Laboratory, Information Directorate (RITB)	Mr. Mark Barnell
Persistent Surveillance Supercomputing	MIT Lincoln Laboratory	Dr. Jeremy Kepner

I ask your assistance and continued involvement to ensure that the HPC assets being acquired under these awards are best employed to meet the specific needs of the selected DHPI projects. Please join me in congratulating the awardees.

André van Tilborg
Deputy Under Secretary of Defense
(Science and Technology)

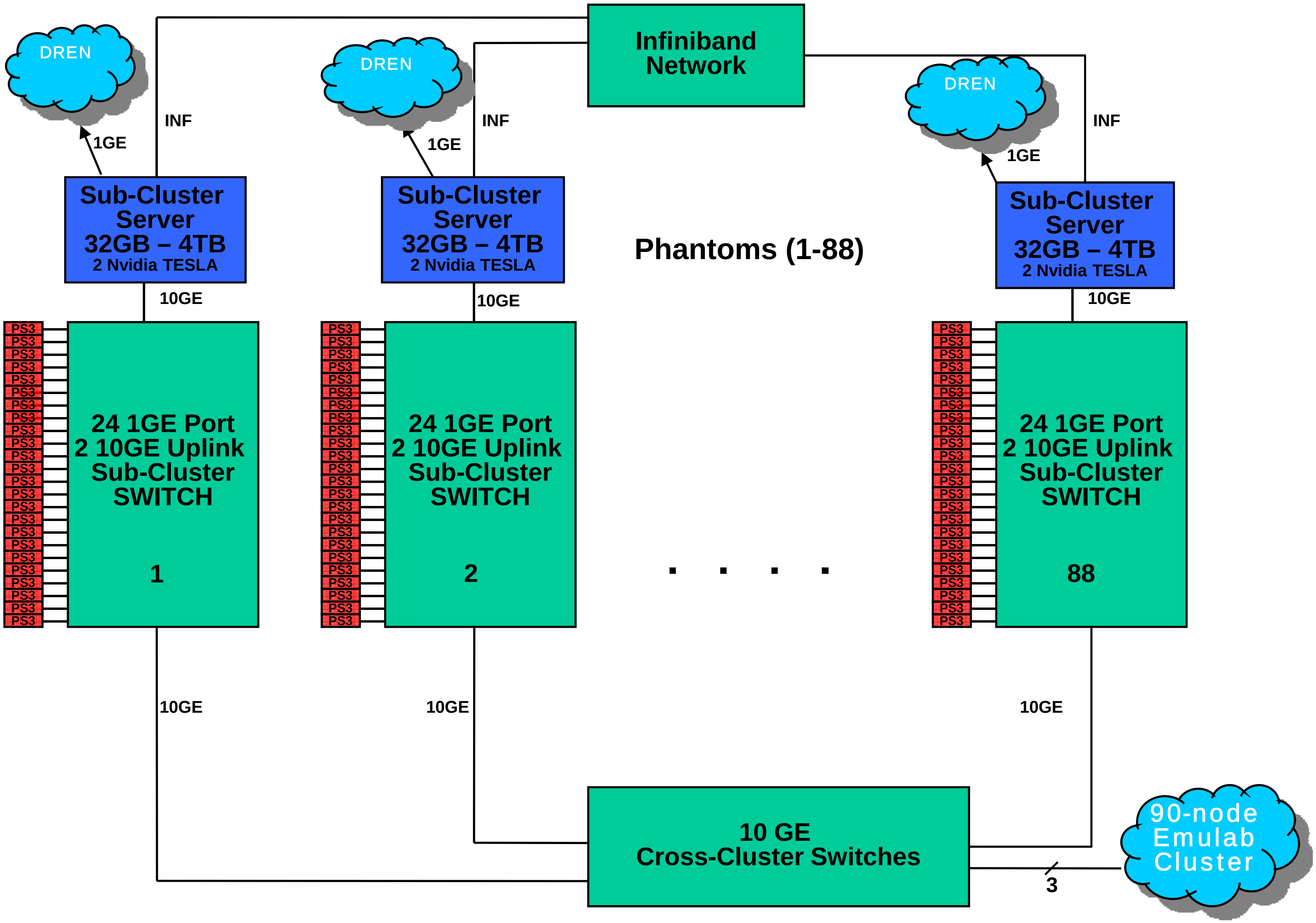
cc:
PD, DDR&E
DoD High Performance Computing Advisory Panel
Project Leaders

Top 500 Supercomputers June 2009

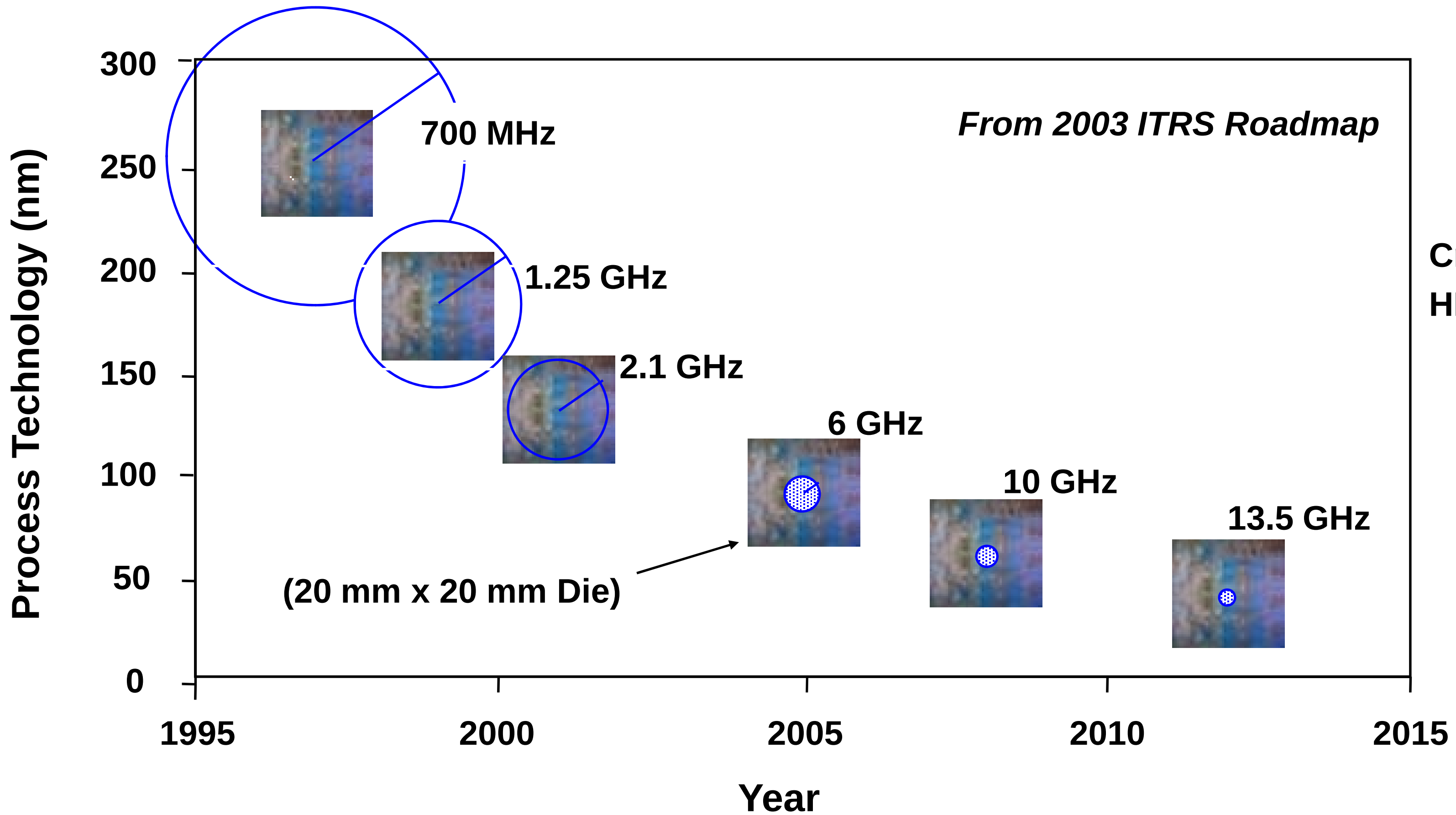
Rank	Site	Computer/Year Vendor	Cores	R_{max}	R_{peak}	Power
1	DOE/NNSA/LANL United States	Roadrunner - BladeCenter QS22/LS21 Cluster, PowerXCell 8i 3.2 Ghz / Opteron DC 1.8 GHz, Voltaire Infiniband / 2008 IBM	129600	1105.00	1456.70	2483.47
2	Oak Ridge National Laboratory United States	Jaguar - Cray XT5 QC 2.3 GHz / 2008 Cray Inc.	150152	1059.00	1381.40	6950.60
3	Forschungszentrum Juelich (FZJ) Germany	JUGENE - Blue Gene/P Solution / 2009 IBM	294912	825.50	1002.70	2268.00
4	NASA/Ames Research Center/NAS United States	Pleiades - SGI Altix ICE 8200EX, Xeon QC 3.0/2.66 GHz / 2008 SGI	51200	487.01	608.83	2090.00
5	DOE/NNSA/LLNL United States	BlueGene/L - eServer Blue Gene Solution / 2007 IBM	212992	478.20	596.38	2329.60

By comparision, the world's largest HPC (Roadrunner at Los Alamos) is 2800 teraflops (single precision) and runs in batch mode.

500 TFLOPS Interactive Cluster (300 Cell, 200 GPGPU)



Range of Wire in One Clock Cycle*



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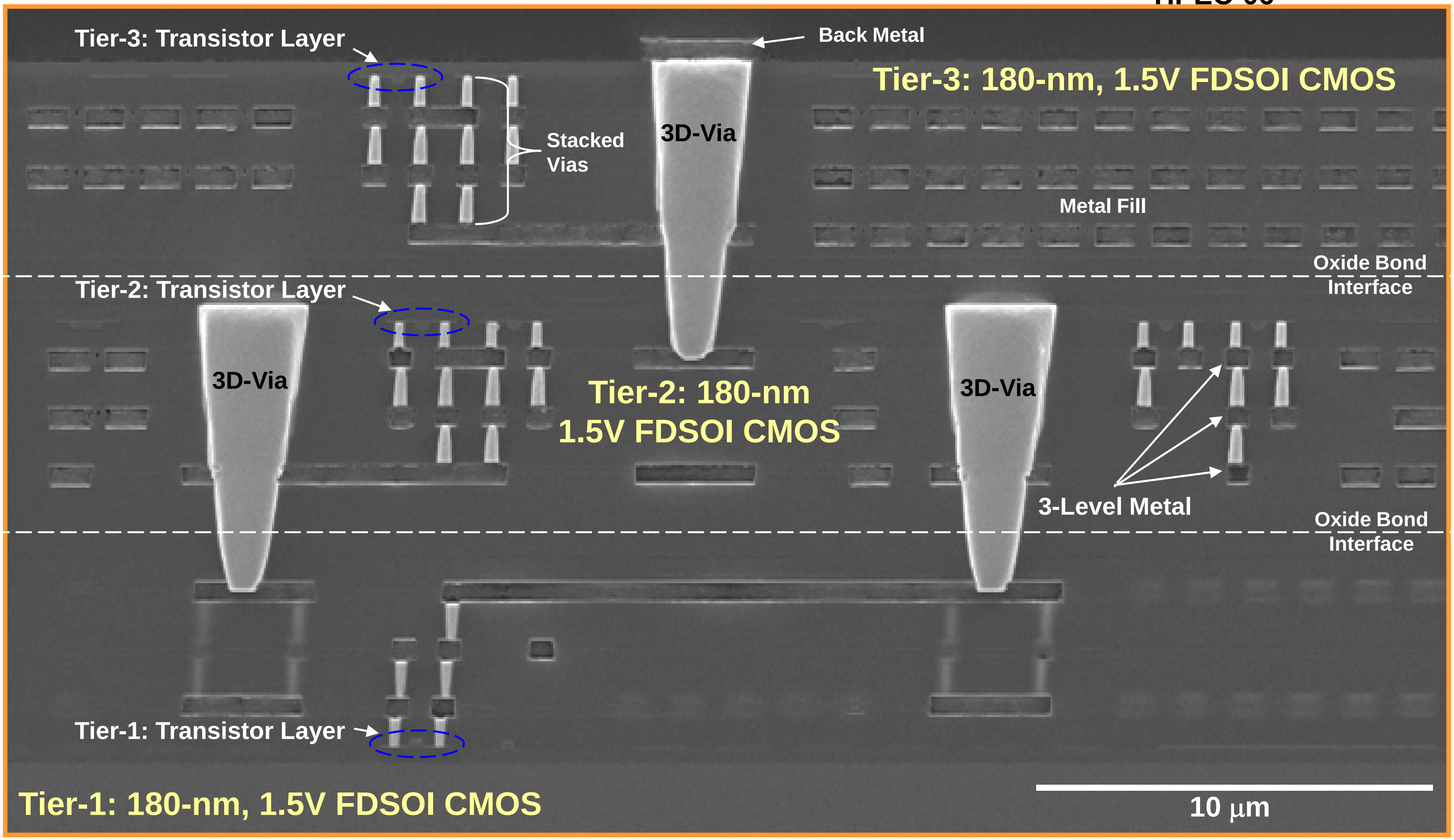
- 3D Integration increases accessible active devices

*After S. Amarasinghe, MIT Laboratory for Computer Science and Artificial Intelligence

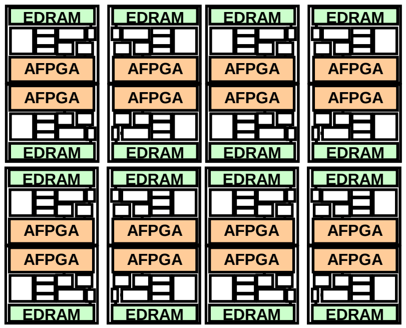
Cross-Section of3-Tier 3D-integrated Circuit

3 FDSOI CMOS Transistor Layers, 10-levels of Metal

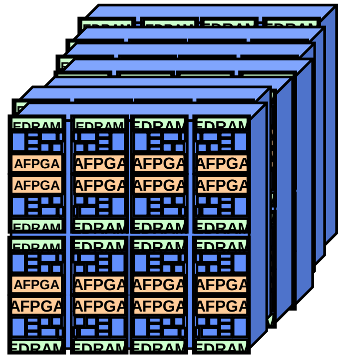
Craig Keast, HPEC-06



Pushing 3D Multicore Architecture



16 cores / chip



50 chips / stack

10 x 10 stacks / board

At 100 GFLOPS/Watt (45 nm):

0.32 watts	**32 watts**	**1.6 kwatts**
16 cores	**800 cores**	**80K cores**
32 GFLOPS Single Precision **16 GFLOPS Double Precision**	**1.6 TFLOPS**	**160 TFLOPS**

Some Daunting HPEC Challenges

Information System Complexity

Physical System Complexity

Autonomous Systems

Fusion, Automatic Target Recognition

Situational Awareness

Keep redoubling the performance/dollar!

But also make the entire HW/SW system timely and affordable

AFRL

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