Game Changing Technologies

Computational Imaging Systems

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The Overall Classification of this Briefing is
UNCLASSIFIED

How the Disruptive Technology Office is Working to Subvert Pre-21st Century Intelligence Business Paradigms

Case Study: Computational Imaging Systems

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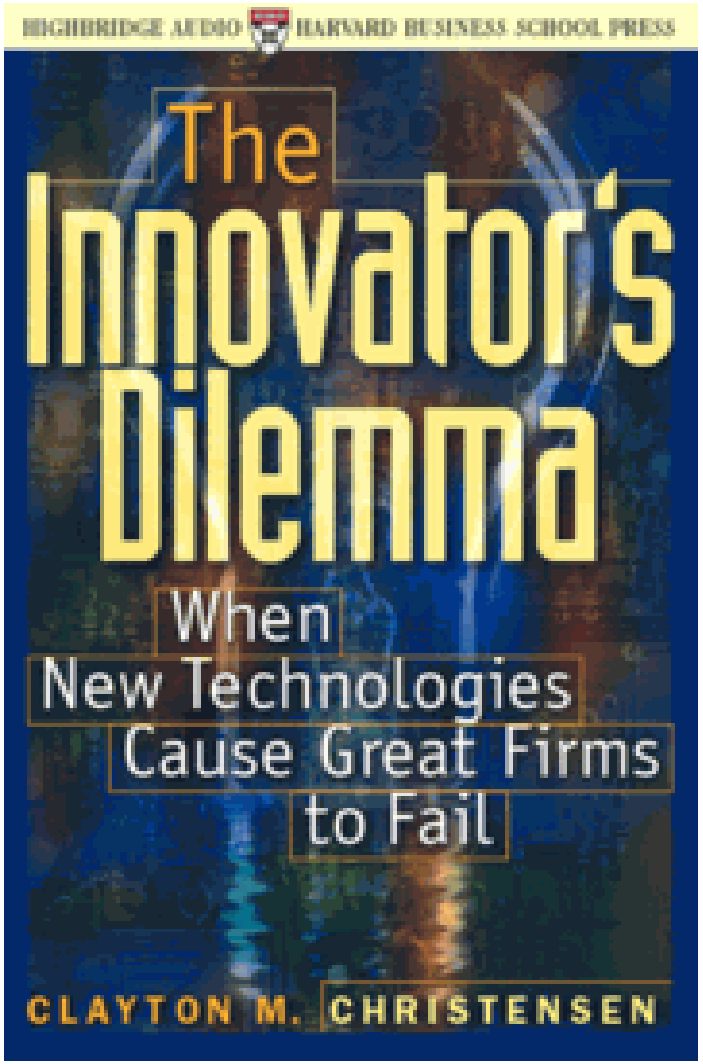
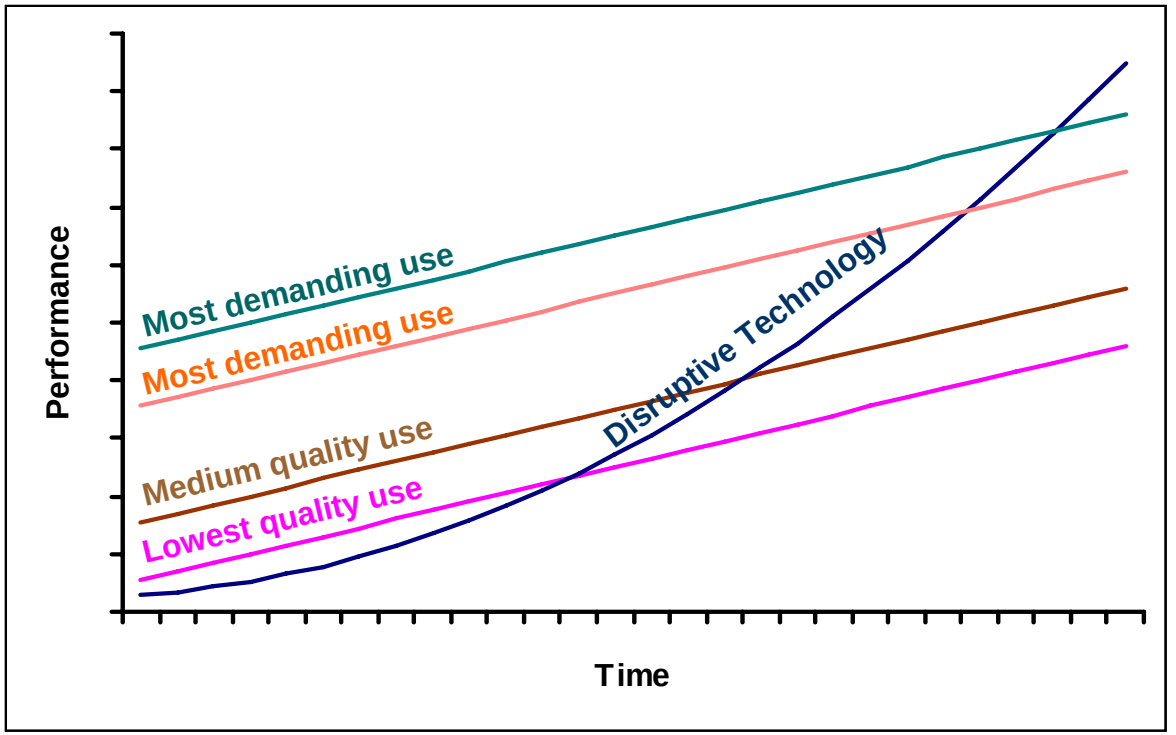
The Nation's Intelligence Community

The Innovator's Dilemma

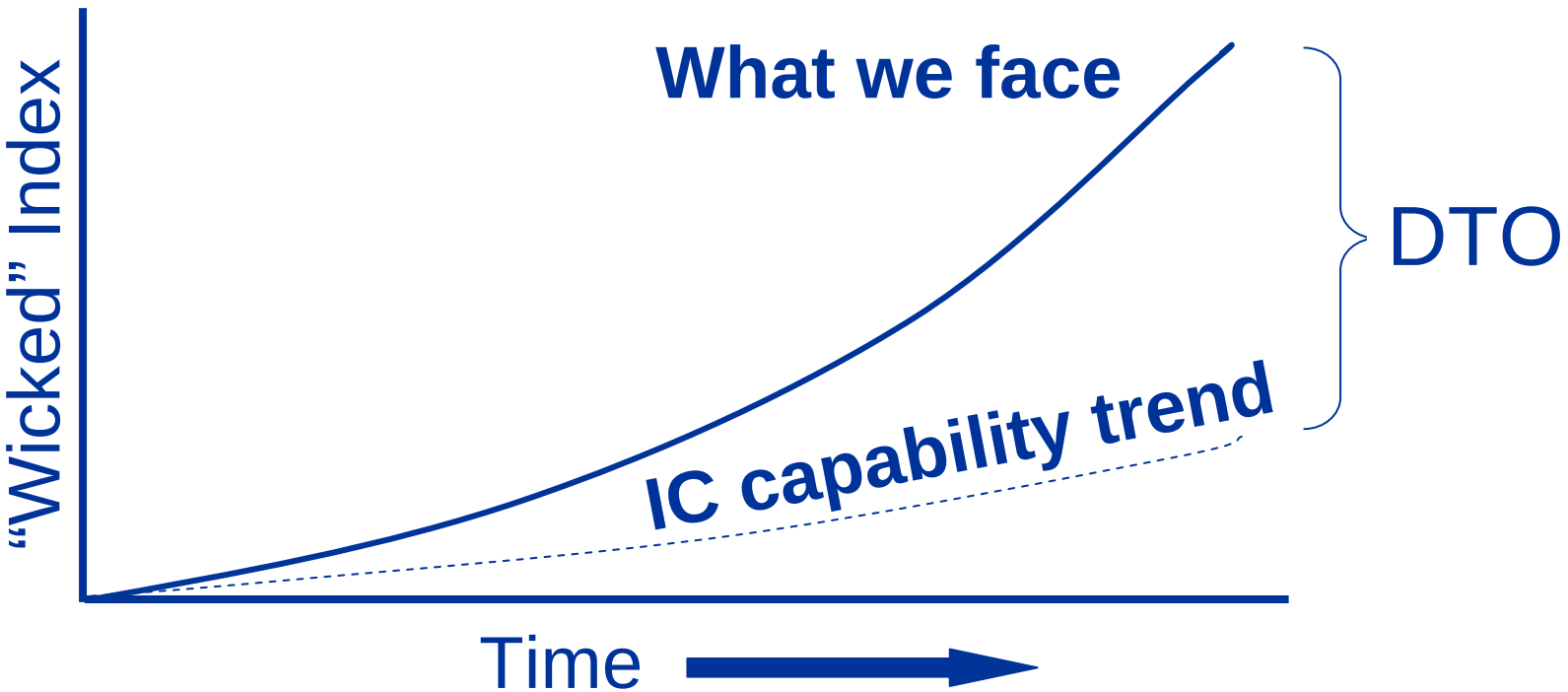


Christensen, Clayton M. *The Innovator's Dilemma*, Harper Business, 1997, 286 pages



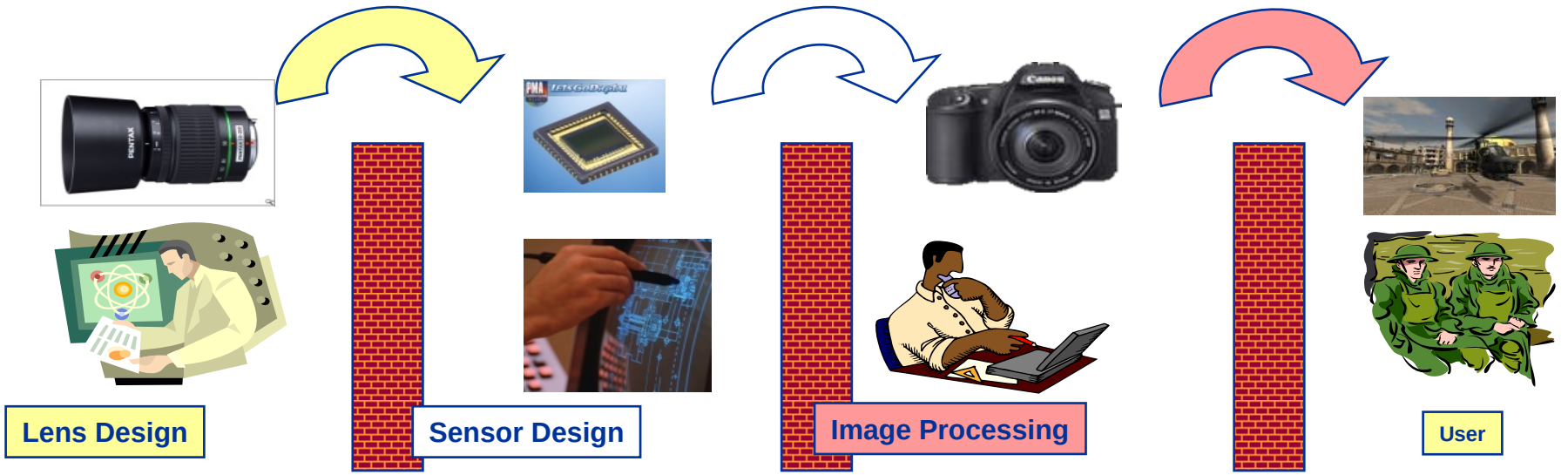
Established Technology	Disruptive Technology
Silver halide photo film	Digital photography
Wireline telephony	Mobile telephony
Manned fighter & bomber aircraft	Unmanned aircraft

DTO Addresses "Wicked" Problems



Conventional Approach to Designing Imaging Sensors

- **Current imaging sensor design strategy:**
  - Separately designed and optimized subsystems/components bolted together
  - Fixed allocation of resources at design time
  - Feed-forward information flow only



Case Study for a Hypothetical Sensor:

Data generated = 1024 x 1024 (spatial) x 200 (spectral) x 8 bits = 200 MB / frame

Information extracted from a typical tactical scene = 100 objects of interest x 4 B/object = 400 B

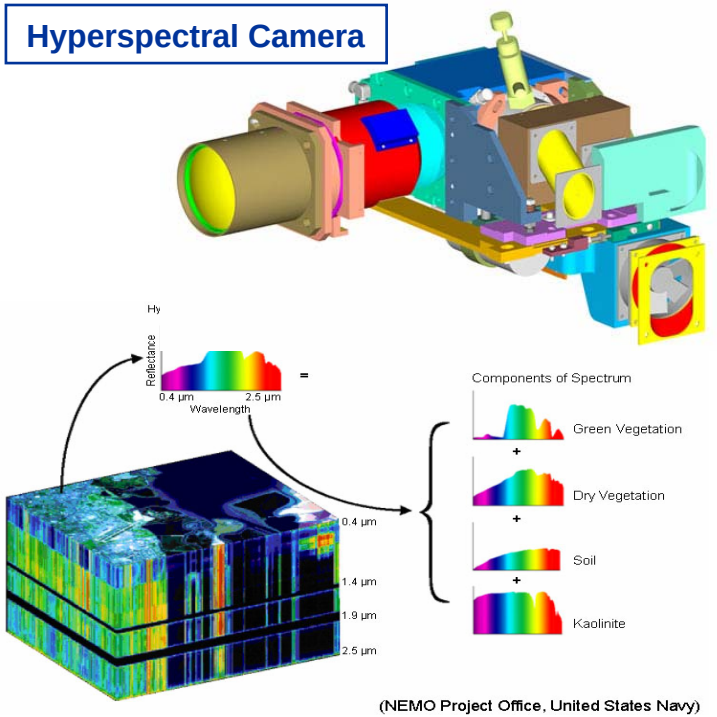
(Information / Data) = 10^{-6} …VERY POOR EFFICIENCY

Current High Performance Imaging Sensors

Predator Camera

Predator Ladar

Hyperspectral Camera



(NEMO Project Office, United States Navy)

39 Megapixel Hasselblad

Technology Scaling Driven by "Moore's Law"

- 3D, hyperspectral, polarimetric, Doppler Ladar….
- More detector pixels, more spectral bands, higher frame rates….
- Governing philosophy: *"More data is better data"*

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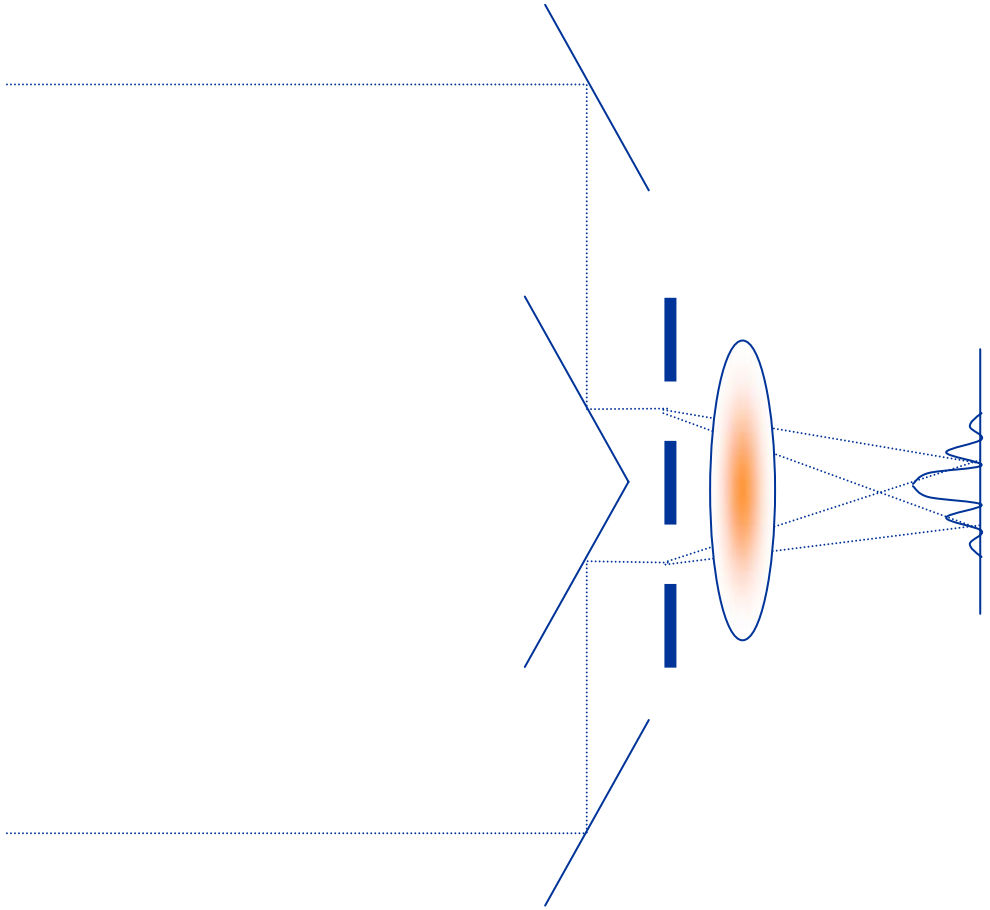
Definition of Computational Imaging Systems

- Sensing systems that exhibit jointly optimized optics, transduction, algorithmic, form factor, power, and information factors which together are tunable and exhibit semi to fully autonomous, purposeful[1] sensing.
- Such systems have experimentally exhibited the following features:
  - Digital super-resolution
  - Depth of field extension
  - Logarithmic dynamic range adjustment
  - Multispectral
  - Low aspect ratio (slim form factors)
  - Polarimetric
  - Wide FOV

[1]*Purposeful sensing:* application-specific sampling with optimal allocation between space, intensity, spectrum…

Oldest Computational Imaging Sensor: Michelson Stellar Interferometer

A. A. Michelson, "Visibility of Interference-Fringes in the Focus of a Telescope," Phil. Mag. 31, 256-259 (March 1891).



VISIBILITY OF INTERFERENCE-FRINGES IN THE FOCUS OF A TELESCOPE.*

By Albert A. Michelson.

When the angle subtended by an object viewed through a telescope is less than that subtended by a light-wave at a distance equal to the diameter of the objective, the form of the object can no longer be inferred from that of the image. Thus, if the object be a disk, a triangle, a point, or a double star, the appearance in the telescope is nearly the same.

If, however. the objective is limited by a rectangular slit, or, better, by two such, equal and parallel, then, as has been shown in a former paper,† the visibility of the interference-fringes is, in general, a periodic function of the ratio of α, the angular magnitude of the source in the direction perpendicular to the length of the slits, and α_0, the "limit of resolution." The period of this function, and thence $\frac{\alpha}{\alpha_0}$, may be found with great accuracy; so that by annulling the greater portion of the objective the accuracy of measurement of the angular magnitude of a small or distant source may be increased from ten to fifty times. As ordinarily understood, this increase of "accuracy" would be at the cost of "definition" (which, in this sense, is practically zero); but if by "definition" we mean, not the closeness of the resemblance of the image to the object, but the accurracy with which the form may be inferred, then definition and accuracy are increased in about the same proportion.

In almost every case likely to arise in practice, the form of the source is a circular disk; and if the illumination over its surface were uniform, the only problem to be solved would be the measurement of its diameter. But in many cases the distribution is anything but uniform. If the curve representing the distribution along the radius be $i = \psi(r)$, then the element of intensity of a strip $y_1 dx$ will be

$$\int_{-y_1}^{y_1} \psi(r)\, dy = \phi(x),$$

* Reprinted, by request, from the *Philosophical Magazine*.

† "On the Application of Interference Methods to Astronomical Measurements" (Phil. Mag., July, 1890).

Automotive Analogy for Imaging Sensors

Horse-drawn Carriage

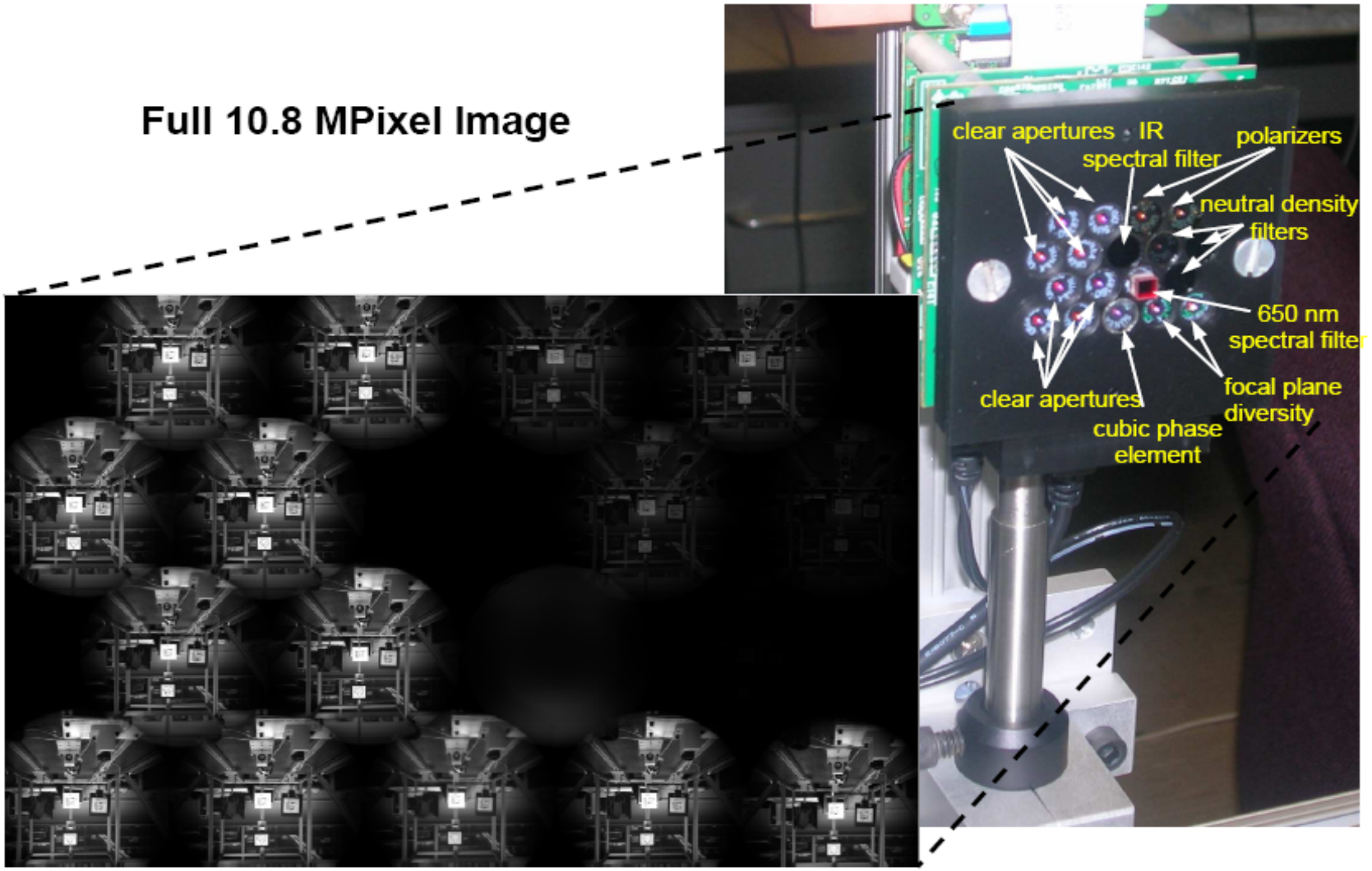
Horse-*less* Carriage

Film Cameras

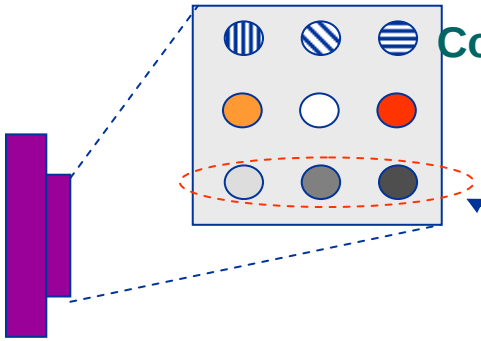
Film-*less* Cameras

Specialization?
Autonomy?

Multi-Aperture, Multi-Diversity Compact Imager: PERIODIC Seedling

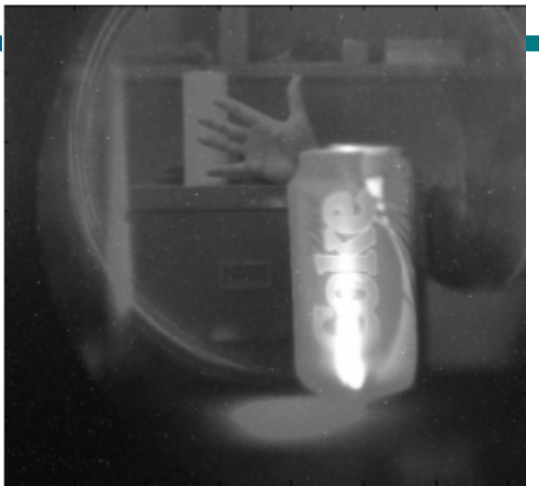


PERIODIC Demonstration

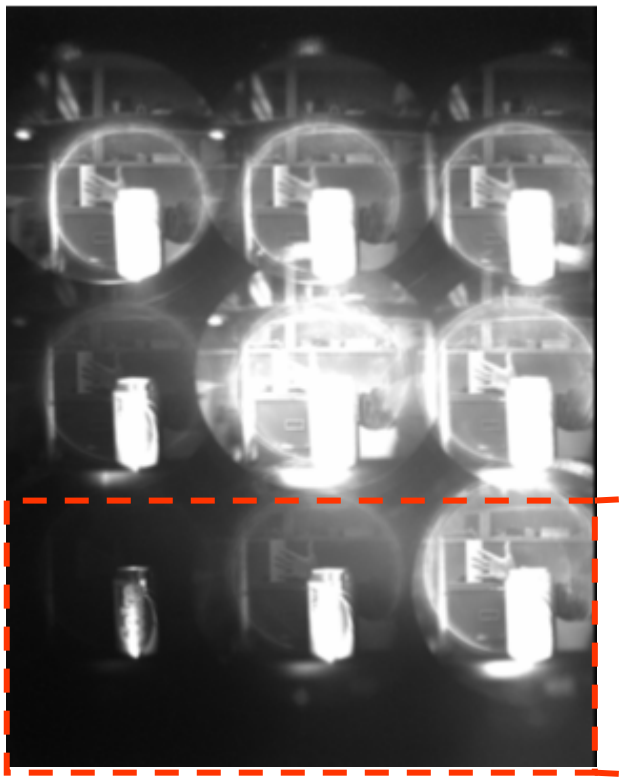


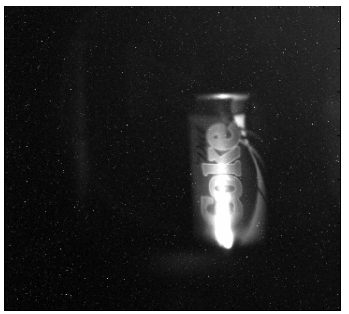
Compound Eye Camera

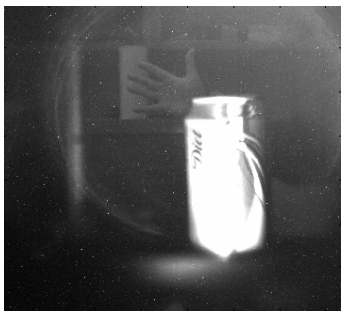
Three neutral density filters.

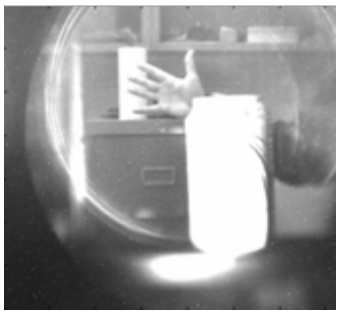


Combining subimages using three different neutral density filters can be used to improve dynamic range



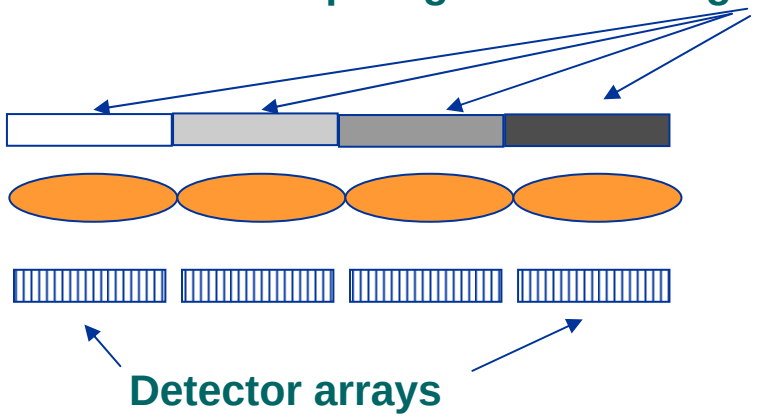






Imaging of High Dynamic Range Scenes – Conventional vs. PERIODIC

Simple light attenuating filters



- Place different neutral density filters in different ‘subimagers.’
- Capture image
- Perform image computation

Moderate exposure time needed to see details in mid-range

Long exposure time needed to see details in shadow regions

Some portions of scene underexposed

Rest of scene overexposed

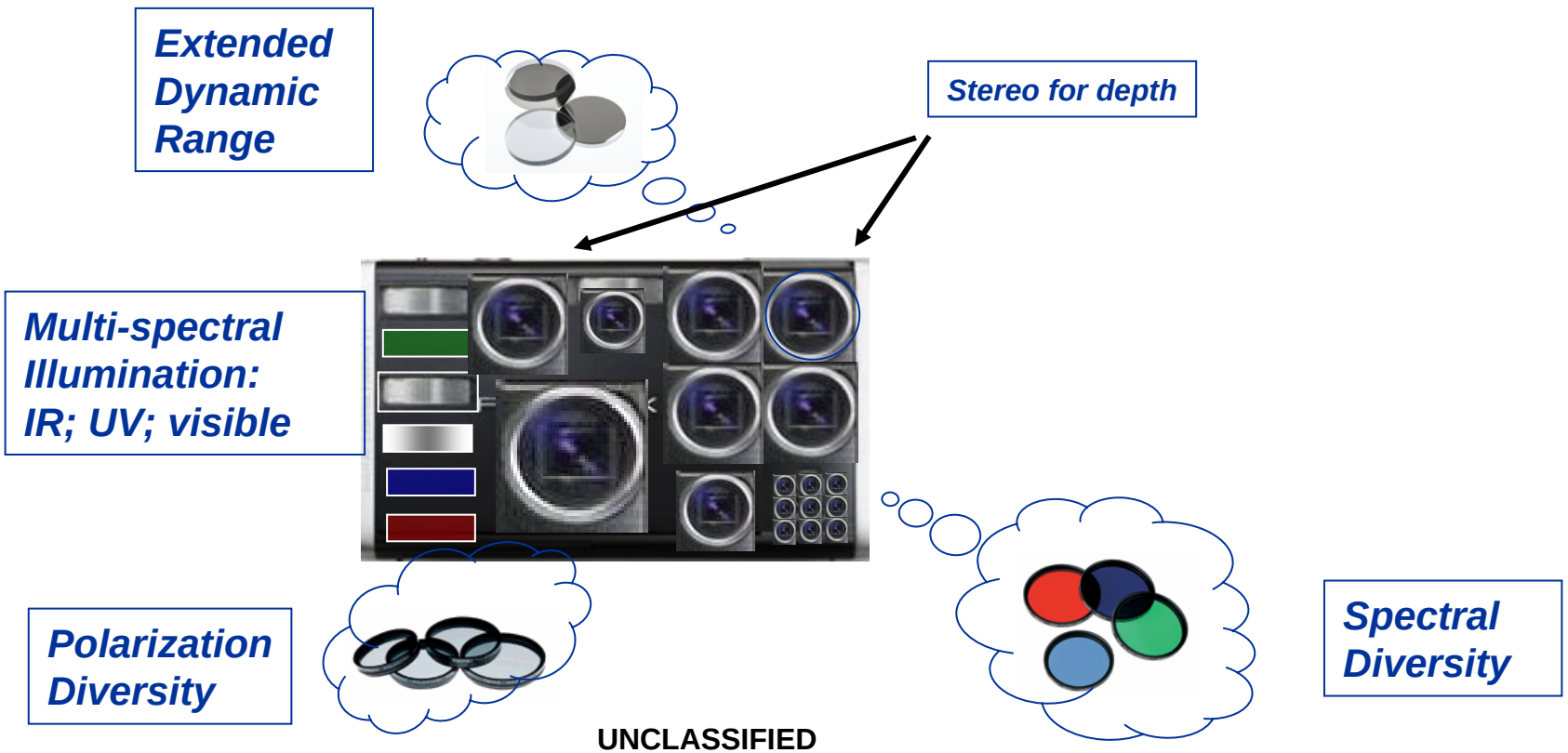
Short exposure time needed to see details in bright regions

Some portions of scene overexposed

Rest of scene underexposed

Next Generation System CONOPS
The "Swiss Army" Imaging System

- Multi-aperture architecture with *dynamic* diversity elements
- Multi-spectral, broad-band sensing (visible-LWIR)
- Multi-band illumination for chem-bio sensing
- Optimized Integration with post-processing and display
- Ultra-thin aspect ratio



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Bottom Line

Computational Imaging Systems =

Nanophotonics + Megapixels + Gigaflops + Form Factor + Power

Jointly designed and optimized

Mission Goal:

Purposeful, Semi to Fully Autonomous Sensing

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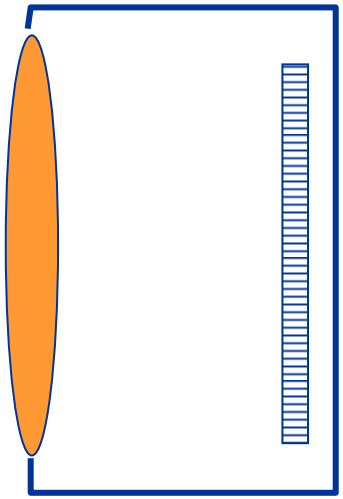
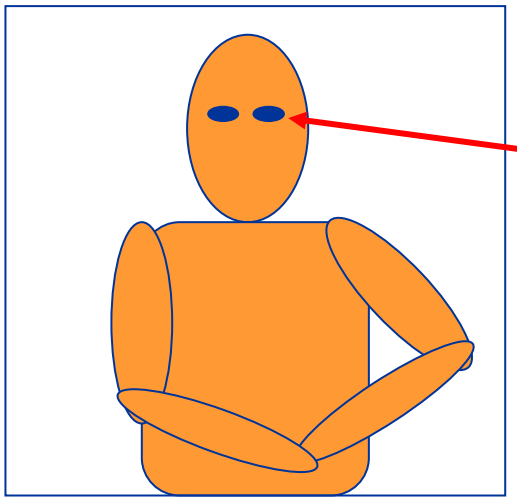
Thank you

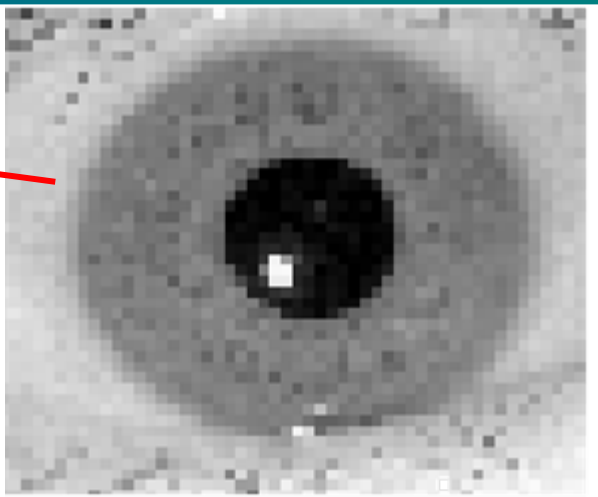
BACKUP

Form Factor Reduction

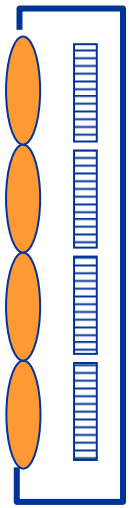
Standard system

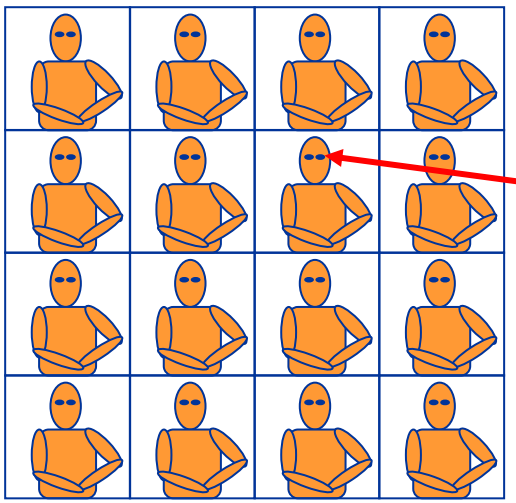


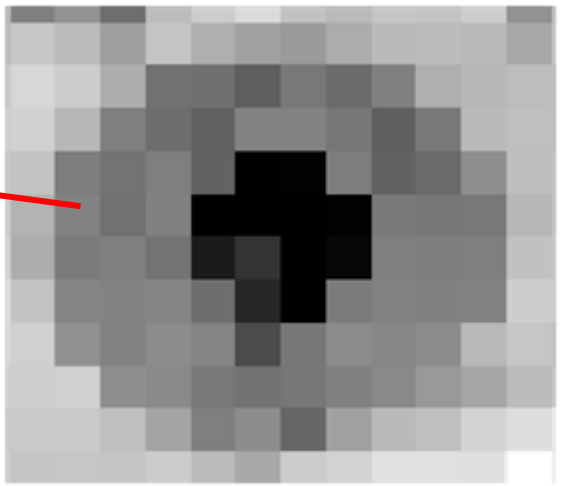




PERIODIC system







If the images are acquired such that they are shifted with respect to each other by subpixel amounts, the full resolution image can be restored subject to noise and other uncertainties.

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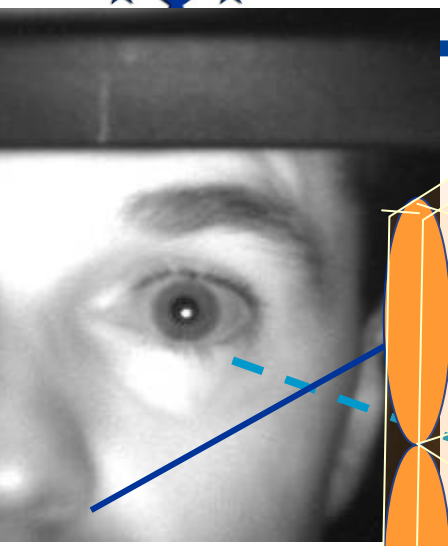
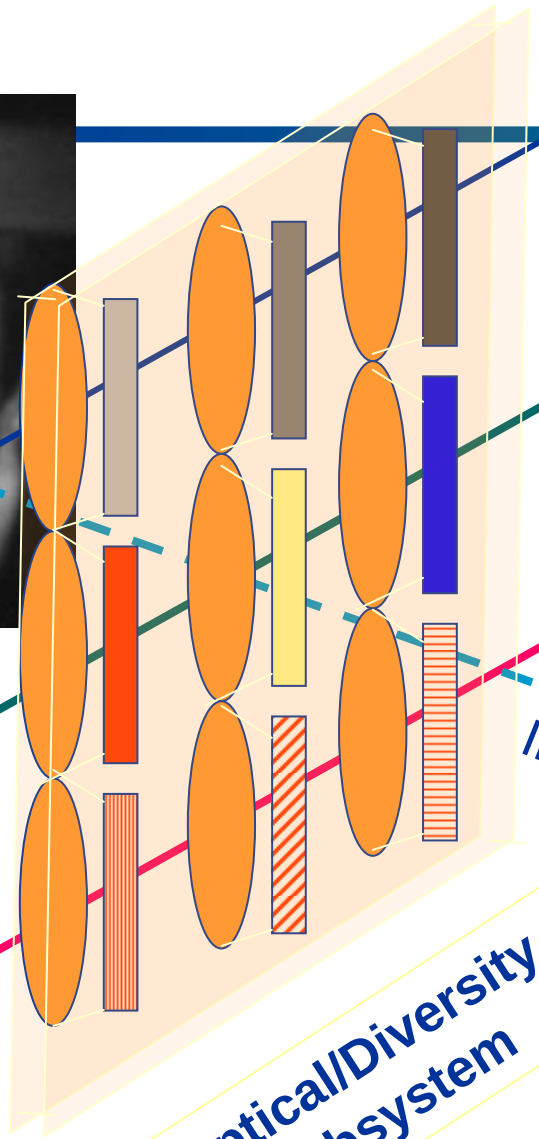
Example of a 3 x 3 Array





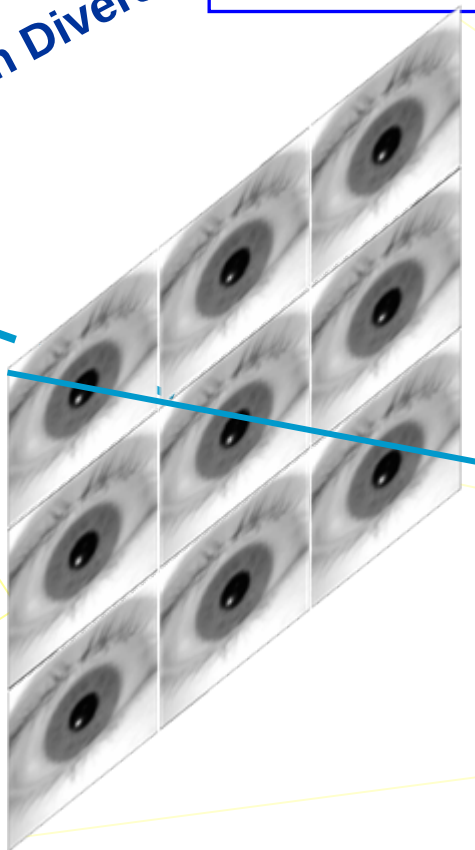
Dynamic Range Diversity

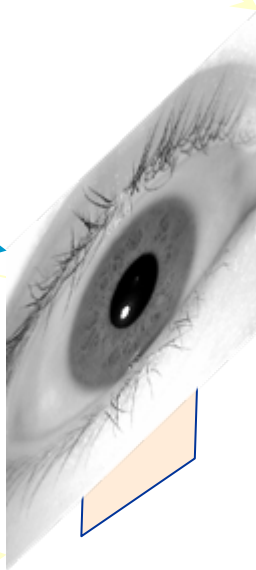
Wavelength Diversity

Polarization Diversity

Imaging Axis

3 x 3 LOW-DEF images post-processed into one or more HIGH-DEF image



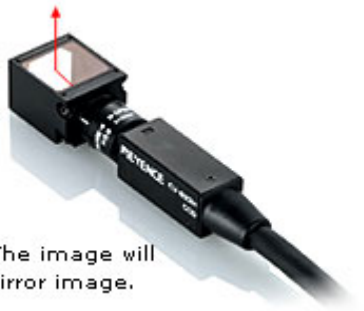


Optical/Diversity Subsystem

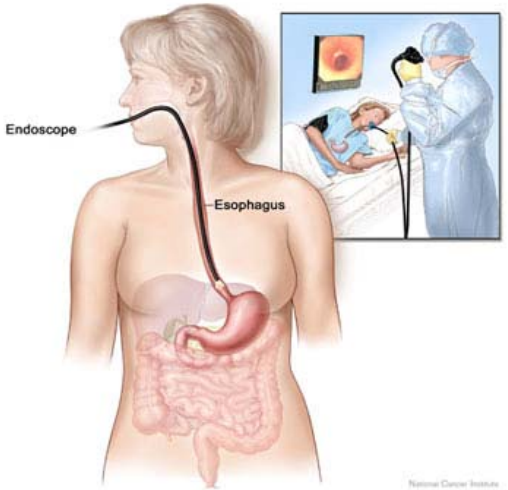
Sensor Array

Digital Cameras….all shapes and forms!

But they all operate the same way



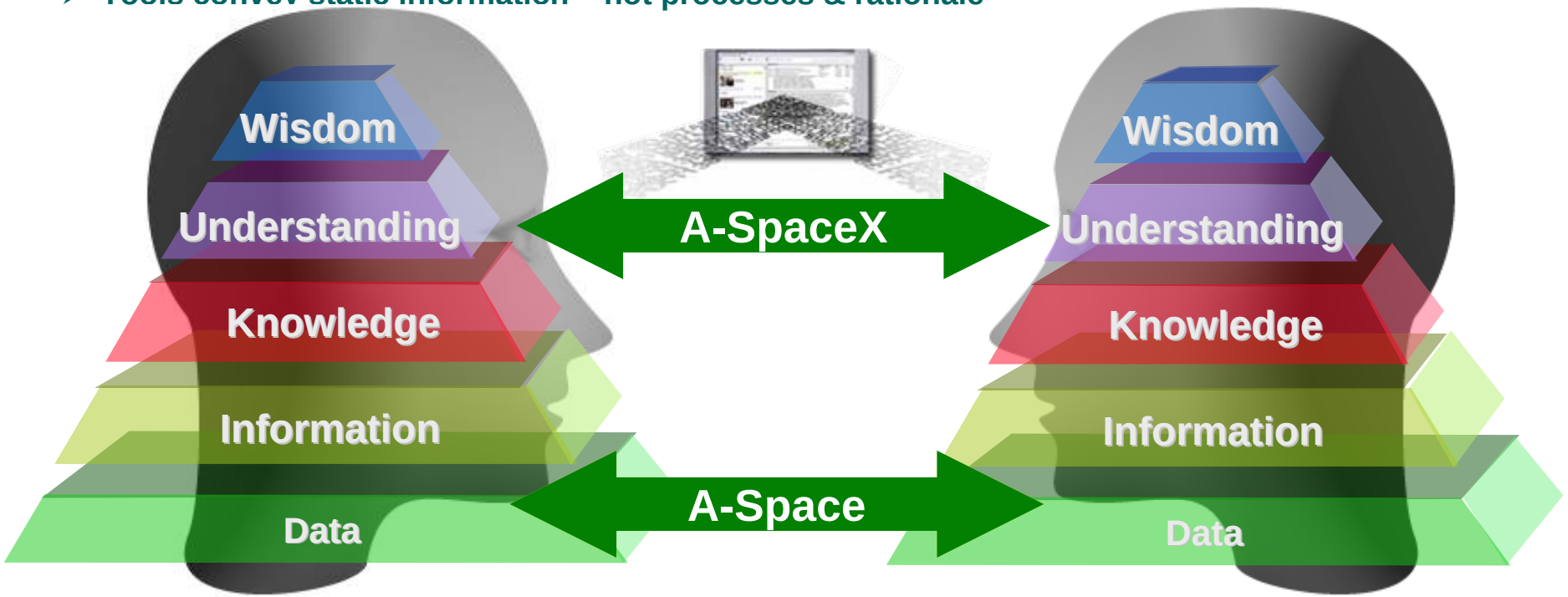
Note: The image will be a mirror image.



MMP Collaborative, Multi-INT Systems

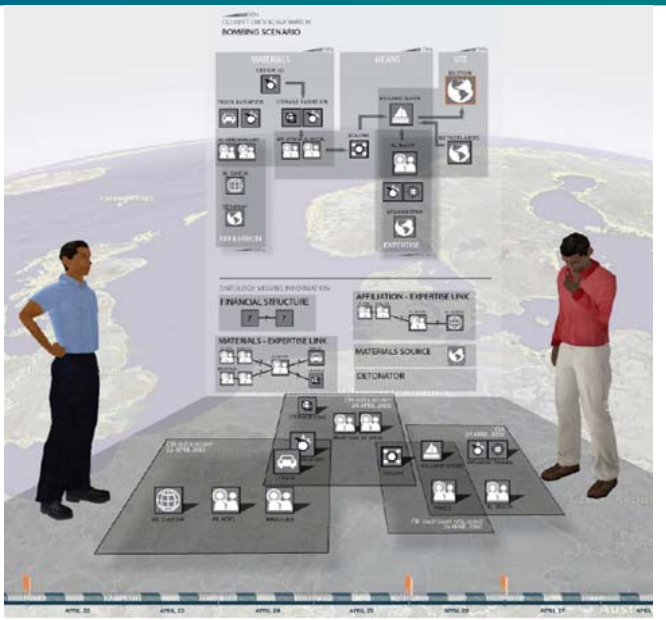
Operational Problems

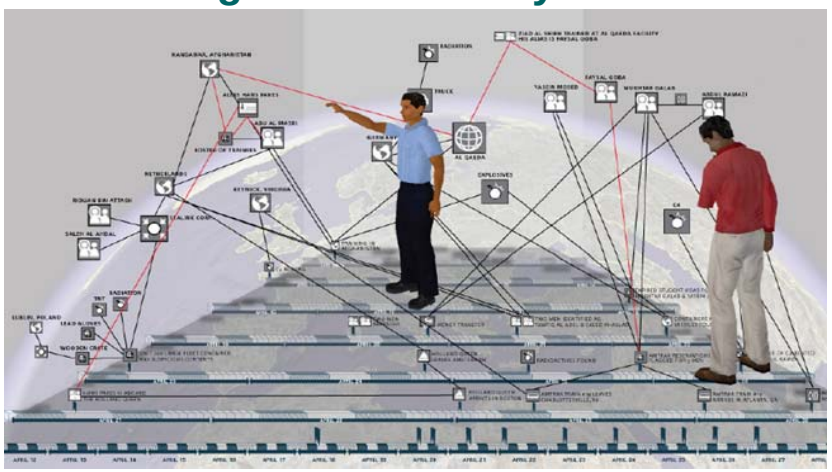
- Too much data – not enough information!
  - Multiple, poorly defined threats make it make it hard to know what is salient.
- Conventional visualizations do not readily support analytic processes
  - Decision making highly branched & iterative characteristic of analytic processes
  - Hypotheses abandoned today may be salient tomorrow
  - Context is key to framing and understanding the problem –
- Sharing is hard – Understanding is collective!
  - Sharing uncertainty is at odds with IC culture
  - Tools convey static information – not processes & rationale



Opportunities

- Web-enabled Technologies
  - Modern & next generation browsers support advanced visualizations
  - Web technologies consistent with Services Oriented Architecture (SOA)
  - Multiple Visualizations readily derived from shared data sources
- MMRPG technology viable
  - Readily available
  - Next-generation analysts are comfortable





- Models maturing
  - Models as games,
  - Models as processes
  - Products inter-operable
- Agent Technologies & Automation
- IC is making major commitments to upgrade infrastructure. (A-Space)

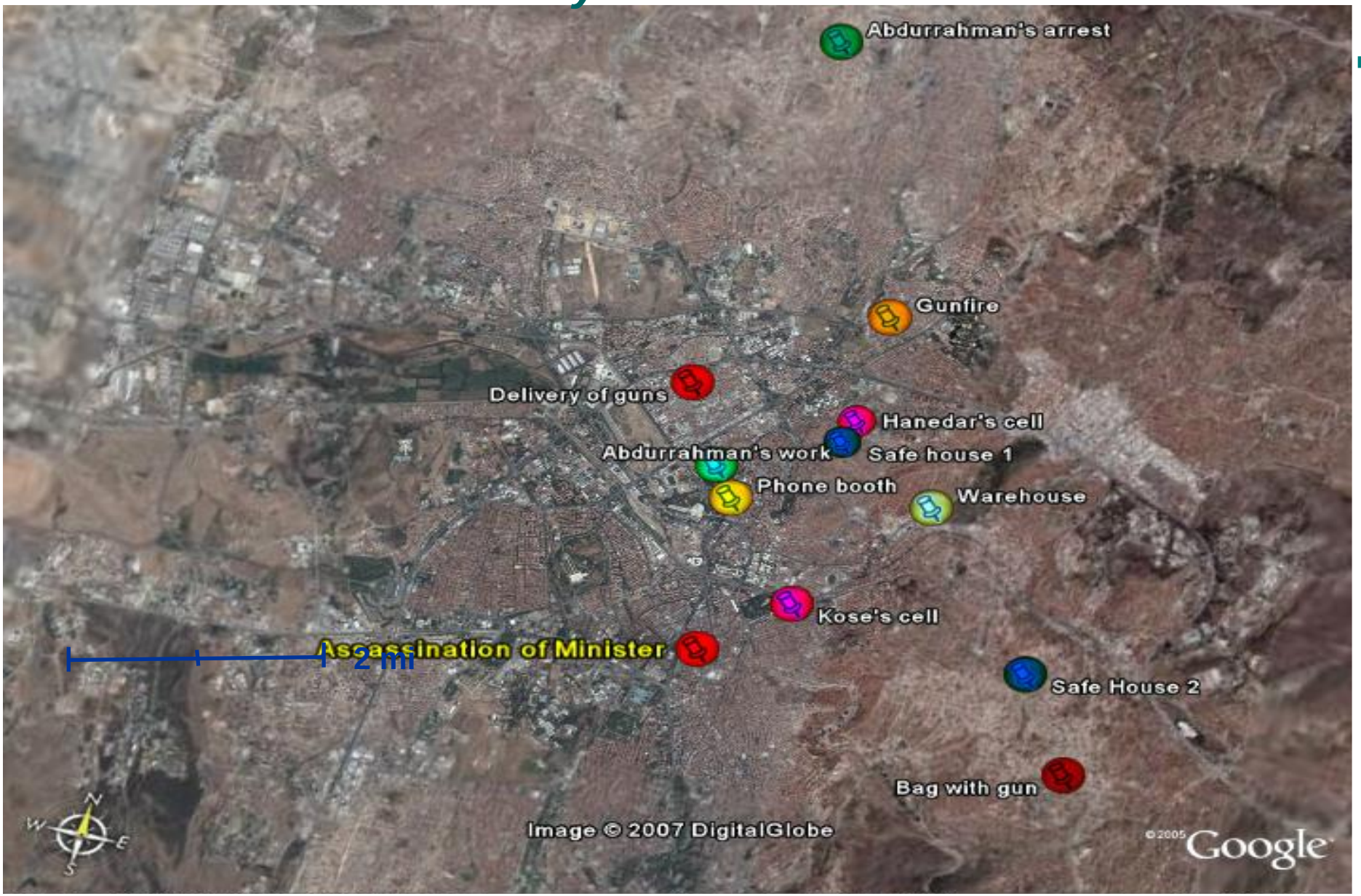
A-SpaceX has a unique opportunity to impact the future of the IC!

DTO

Example Environment

Geospatial Profiling for Counter-Terrorism

Geospatial Profiling for Counter-Terrorism
Case Study: Assassination of Turkish Minister



Proactive Intelligence Analysis

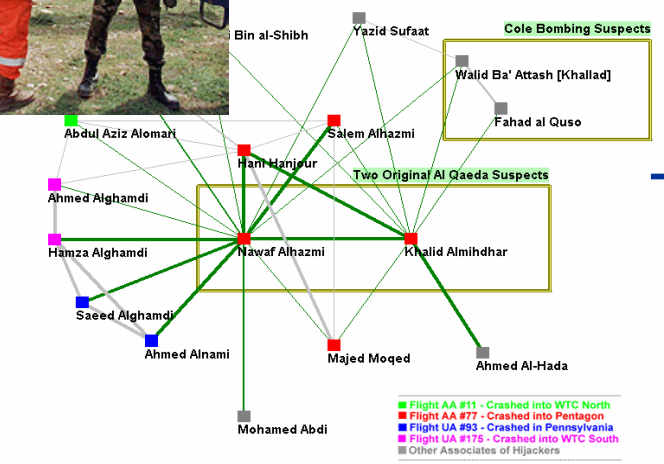
Why Proactive Intelligence (PAINT)?

Cyber attack

Weeks to recover

Bioterrorism

Pandemic in days



Terrorism Attack

Disruptive Change

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Proactive is Essential

Smallpox attack exercise without proactive warning or plans has dire consequences

- **Rotterdam port, world's 2nd largest, closes**
- **Polish citizens stream to Germany for scarce vaccine**
- **Debate on closing borders, quarantining cities, and limiting the movement of people**
- **World Health Organization lacks authority**

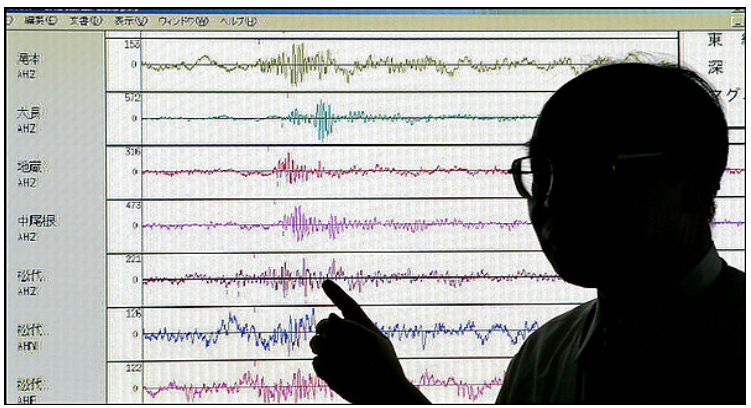
ATLANTIC STORM

PAINT's Approach

❑ Project Forward

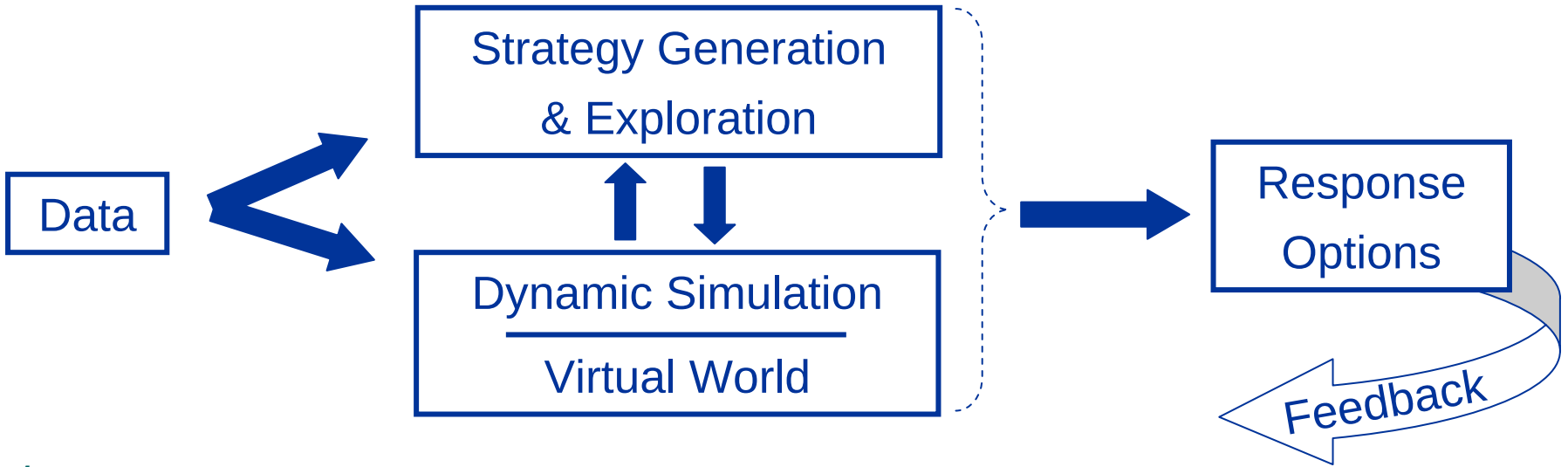
Doomsday Clock moves closer to midnight by two minutes due to nuclear weapons programs in Iran and North Korea.
-February 25, 2007, Board of Directors of the *Bulletin of the Atomic Scientists*

- Explore strategies & identify response points



- Monitor test areas
- Disrupt supply chain
- UN trade ban re uranium enrichment
- UN diplomatic & economic incentives
- US financial sanctions

What's New in PAINT's Approach?



Near-term

Timely: Rapid ID of causal relationships in diverse data sets

Mid-term

Adaptive: Construct models to handle sparse & ambiguous data

Semi-autonomous: cultural, environmental & threat models formulated with "light touch"

Integrated: Strategy tests with dynamic simulations & virtual worlds

Goal

Project future threat developments and identify response options