



Cooperative Microsystems

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“Cooperative Microsystems”

Adel A. M. Saleh

DARPA / MTO

4 March 2009

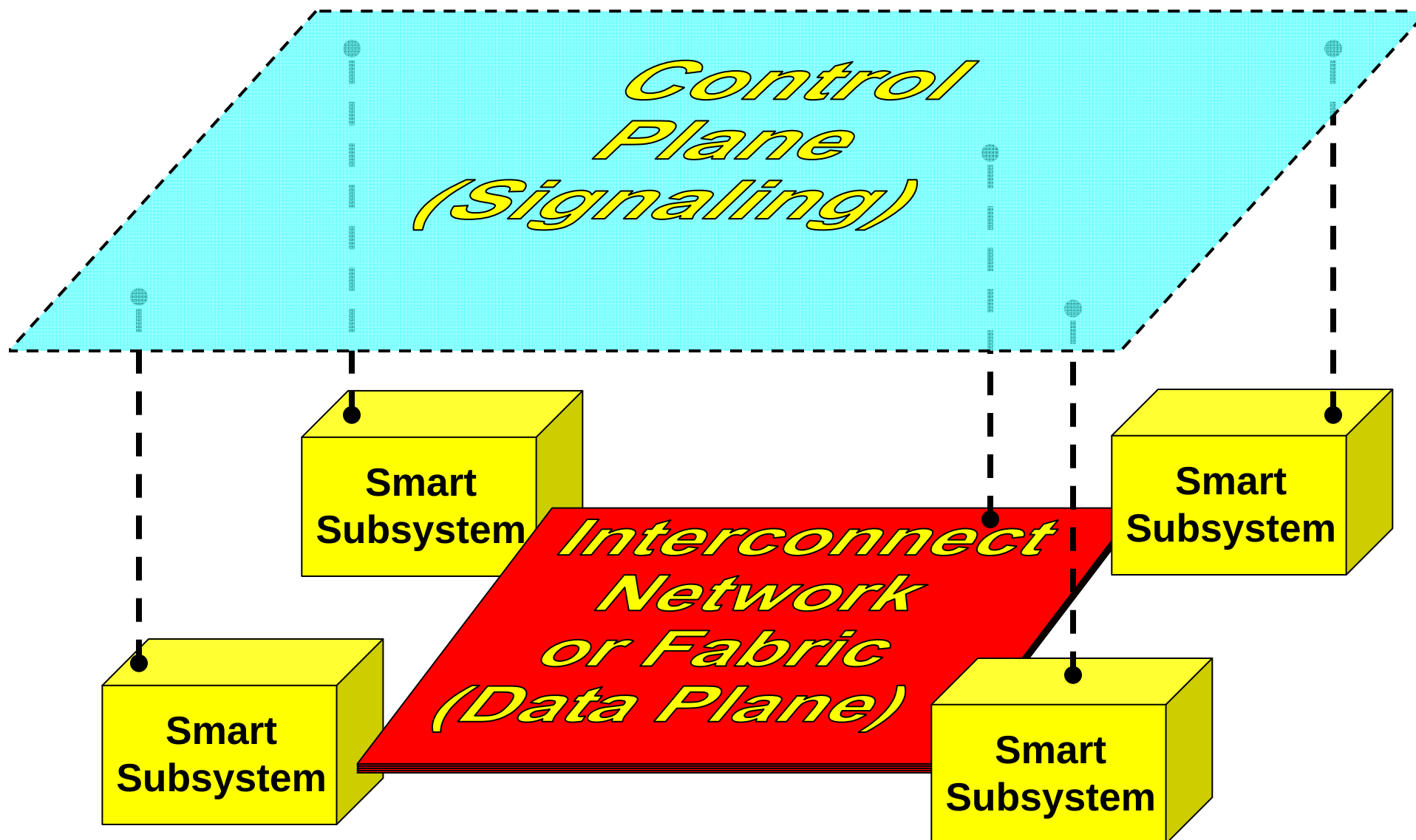


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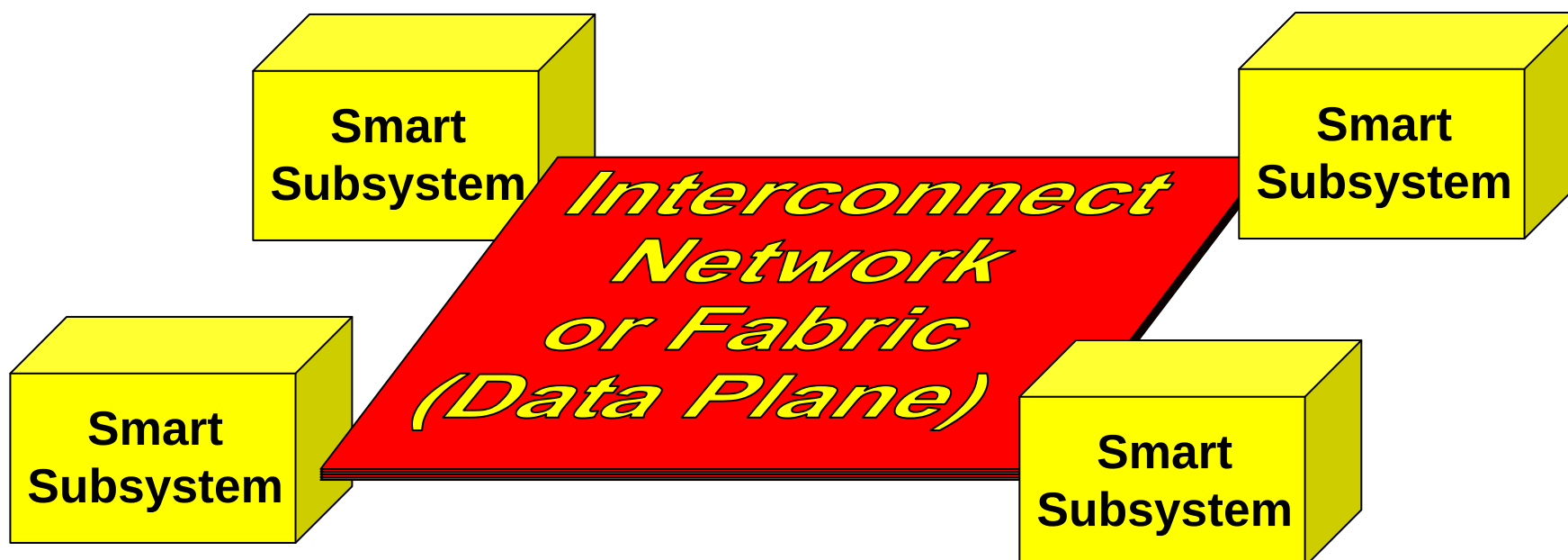


Definition of a Cooperative System





Definition of a Cooperative System





A Cooperative **Mega-System** (Global-Scale IP/Optical Network)



DARPA CORONET Program

The Network Nodes **Cooperate** to Accomplish:

- Fast, automatic end-to-end provisioning of IP and Optical Services
- Fast, automatic recovery from multiple network failures (self healing)
- Secure, low blocking, low latency, high efficiency, and huge capacity

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Let Us Shrink the Network by Factors of 10 Each Case is a Cooperative System of Its Own



~5,000 km



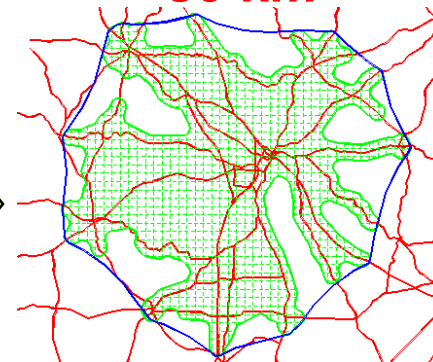
Wide-Area Network (WAN)

~500 km



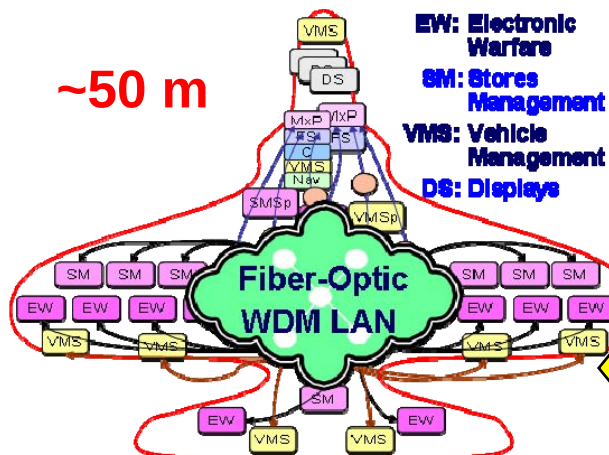
Regional Network

~50 km



Greater Metropolitan-Area Network (MAN)

~50 m



WDM Local-Area Network (LAN) for Avionic Platforms
DARPA NEW-HIP Program

~500 m



Campus-Scale Local-Area Network (LAN)

~5 km



Metropolitan-Area Network (MAN)



Outline of the Rest of the Talk



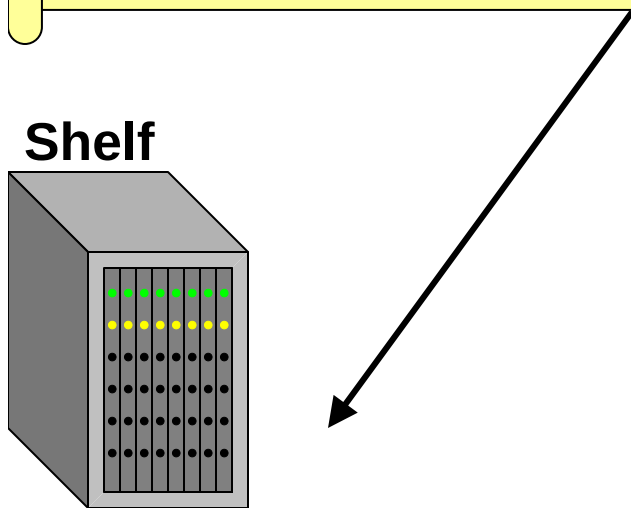
- A Vision for the Next-Generation, High-Performance Cooperative Microsystems Consisting of Chips, Cards, Shelves and Racks
- Chip-to-Chip Optical Interconnects
 - *Current and Future Vision*
- On-Chip Cooperative Microsystems
 - *We will hear two talks on this*
- Summary of the Vision
- Quantum-Scale Cooperative Microsystems
 - *We will hear two talks on this*
- Biological Cooperative Microsystems
 - *We will hear one talk on this*



A Vision for the Next-Generation, High-Performance Cooperative Microsystems



The Heart of the Vision is Configurable, Optical, WDM-Based Interconnects to Realize a Plug-and-Play, Multi-Terabit Bus



Shelf

Optical
Backplane

Micro-
Chips

Cards

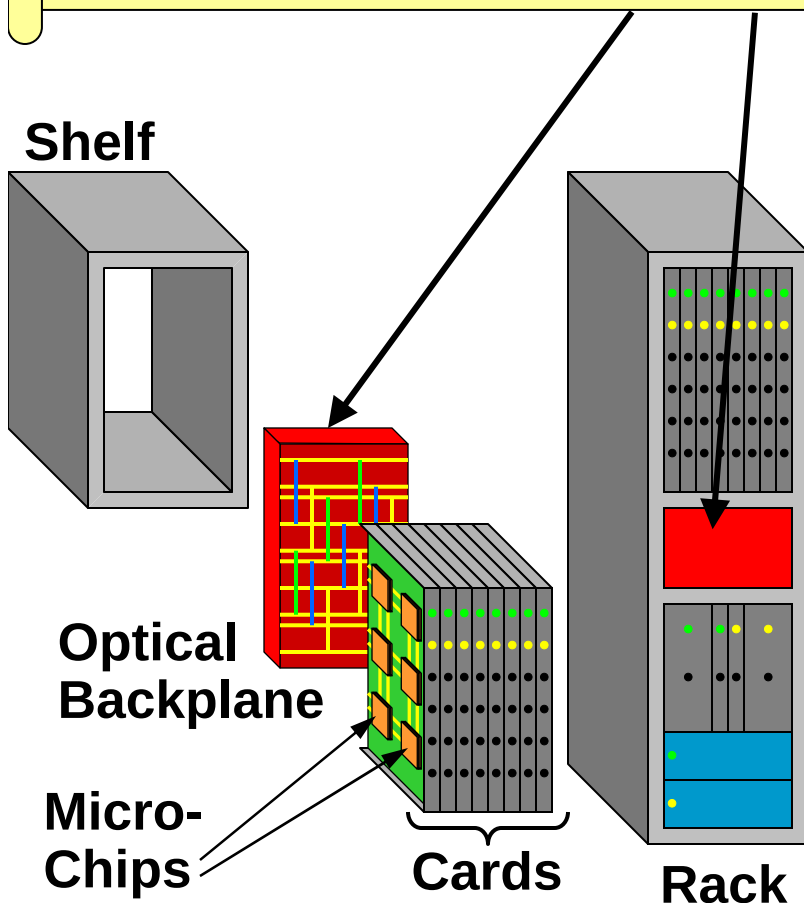


A Vision for the Next-Generation, High-Performance Cooperative Microsystems



The Heart of the Vision is Configurable, Optical, WDM-Based Interconnects to Realize a Plug-and-Play, Multi-Terabit Bus

Let us now build
a Multi-Shelf Rack

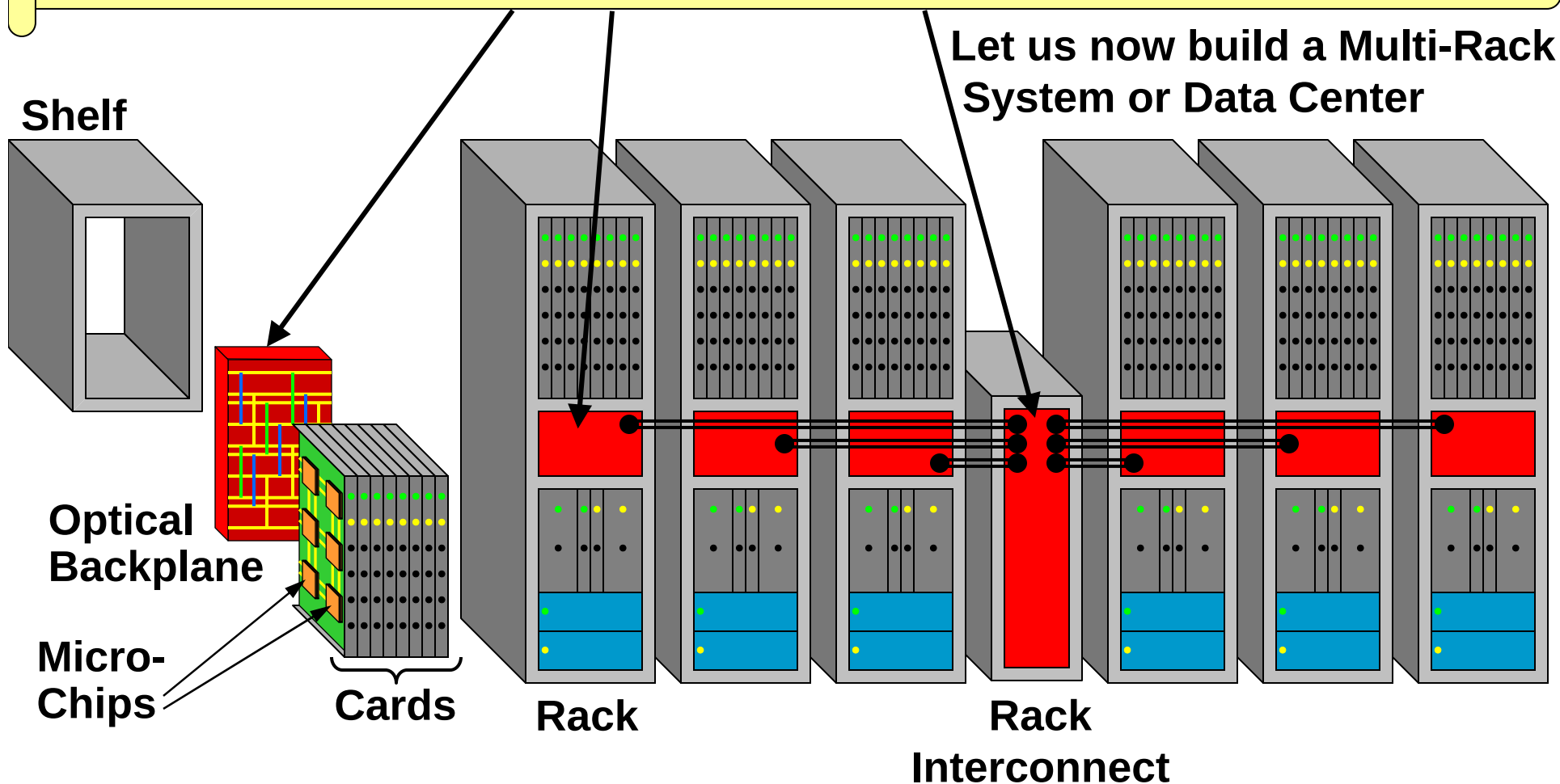




A Vision for the Next-Generation, High-Performance Cooperative Microsystems

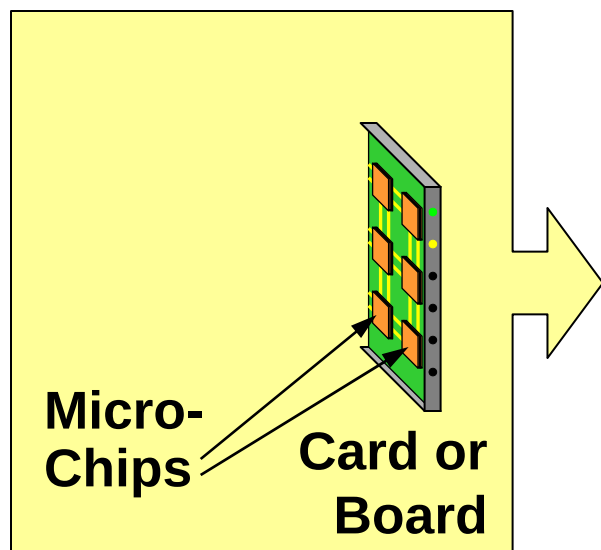


The Heart of the Vision is Configurable, Optical, WDM-Based Interconnects to Realize a Plug-and-Play, Multi-Terabit Bus

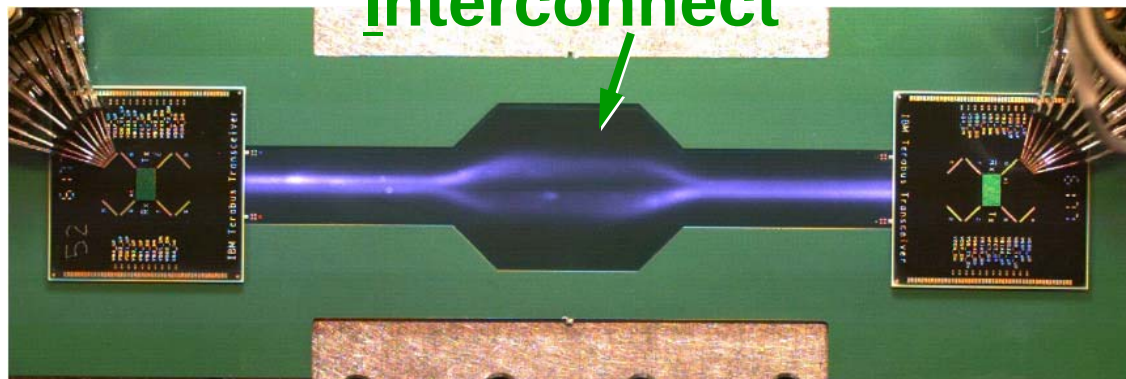




Pushing the Vision Down to the Board and Chip Levels



Chip-to-Chip Optical Interconnect

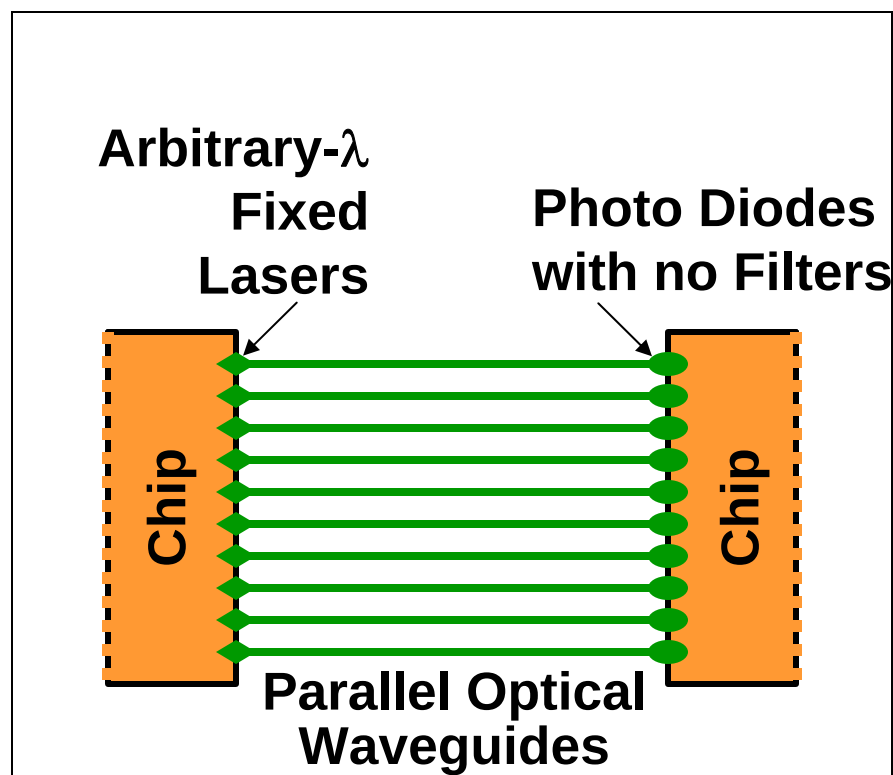


The DARPA C2OI Program

- Board-level and off-board, chip-to-chip optical communication
- Utilizing an array of VCSEL transmitters, parallel waveguides, and photo-diode receivers
- Enables higher bandwidth ($\gg 1$ Tbps) and lower power (5 pJ/bit) communication as compared to electronic alternatives.
- Do we need to add WDM and Configurability to this Vision ?

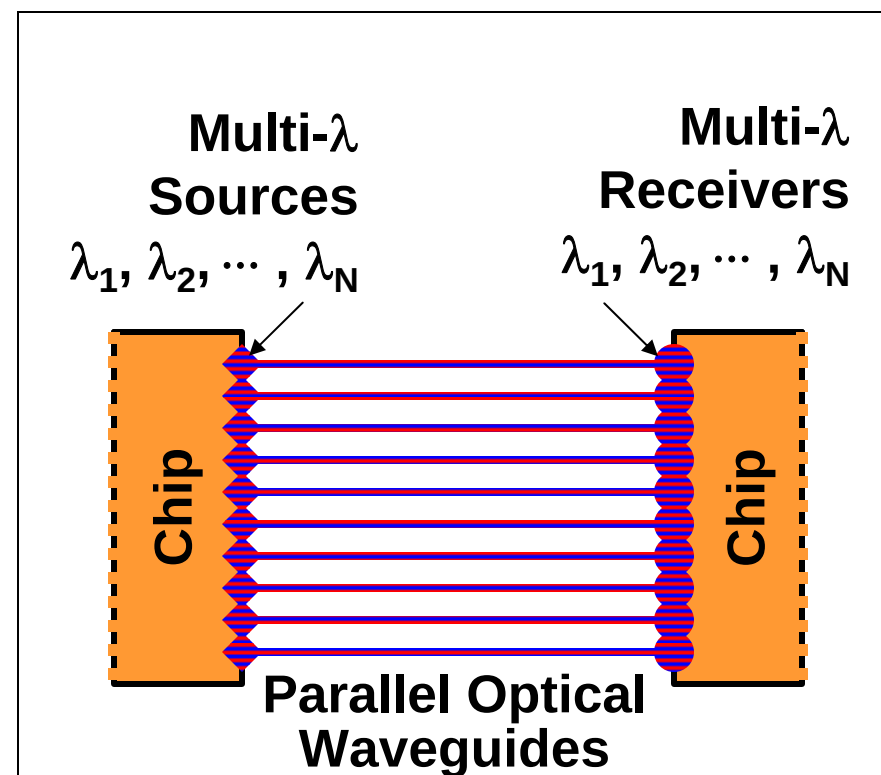


Why/How to Add WDM and Configurability ?



Static, Parallel Optical Interconnect

** Reference architecture*

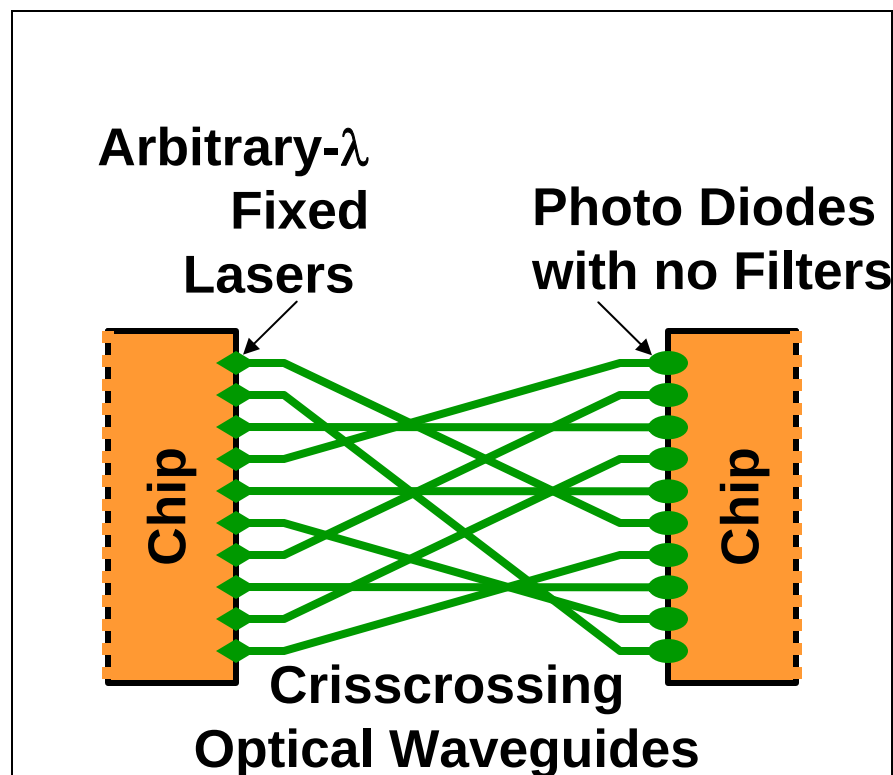


Use WDM to Increase Capacity ?

- * Multi-λ transmitters and receiver are large and power hungry*
- * I do not believe that this is why one would want to do WDM*

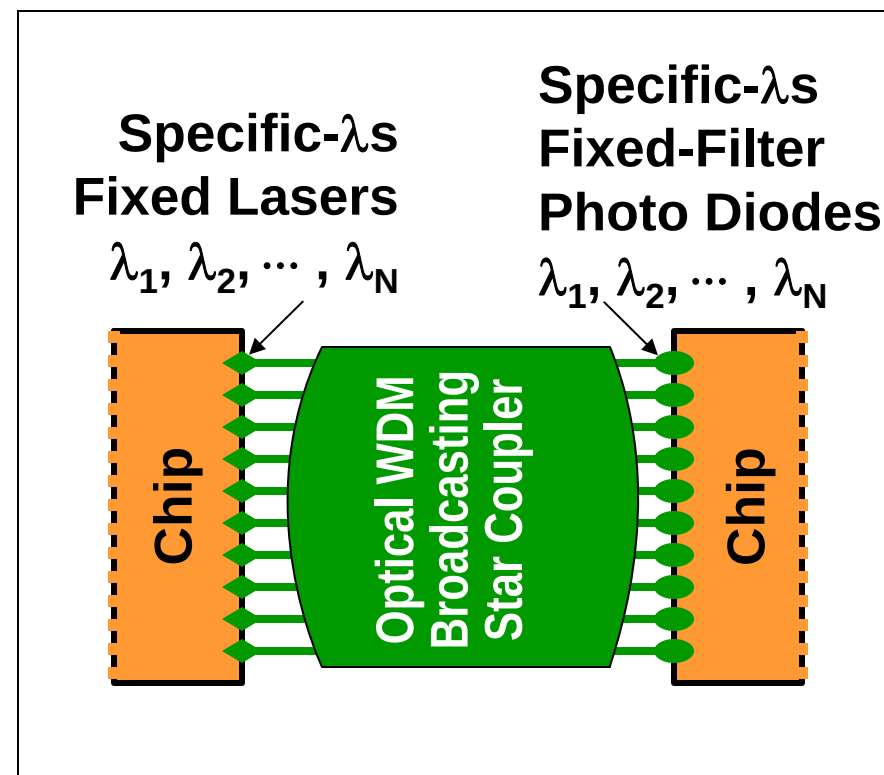


Why/How to Add WDM and Configurability ?



Crisscrossing Optical Interconnect

- * *Hard to fabricate crossing waveguides with low loss and low cross-talk*
- * *Once made, interconnection is static*
- * *Not an elegant solution!*

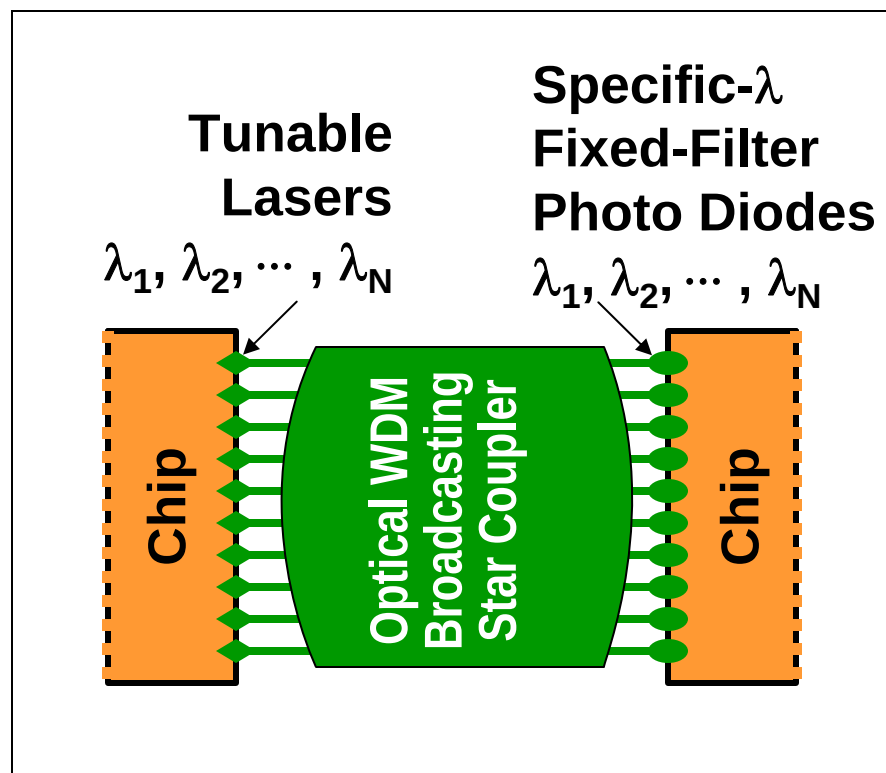


Crisscrossing Optical Interconnect

- * *More elegant solution*
- * *But, we need specific-λs, fixed lasers and filters for this vision*
- * *Nominal loss = 1/N*
- * *WDM in the fabric, not at the ends*

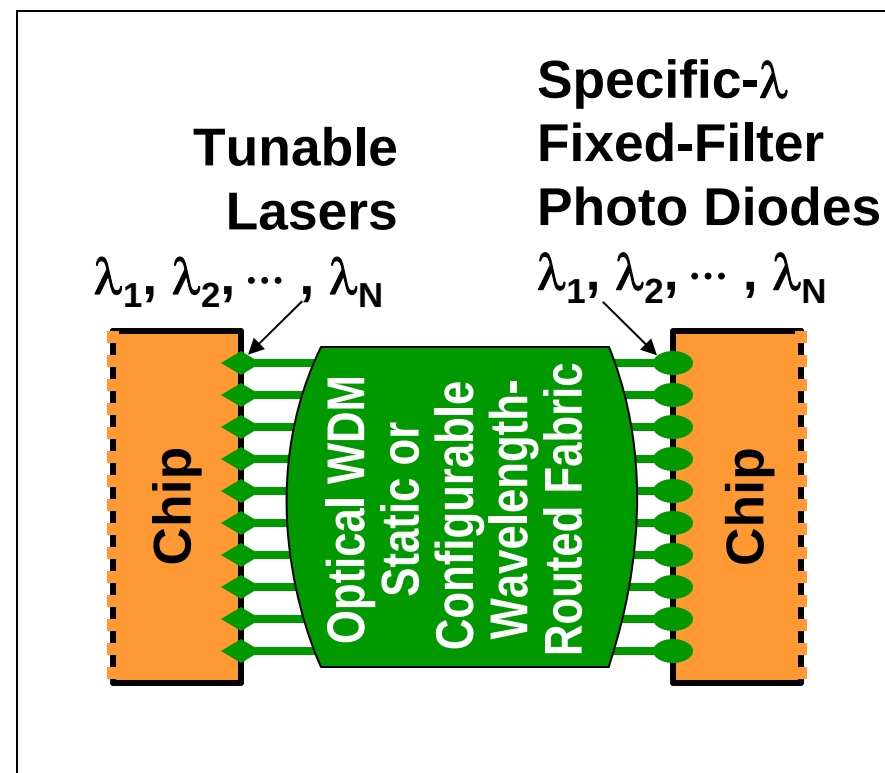


Why/How to Add WDM and Configurability ?



Configurable Optical Interconnect

- * *We need tunable lasers and specific- λ s fixed filters for this vision*
- * *Nominal loss = $1/N$*
- * *WDM in the fabric not at the ends*

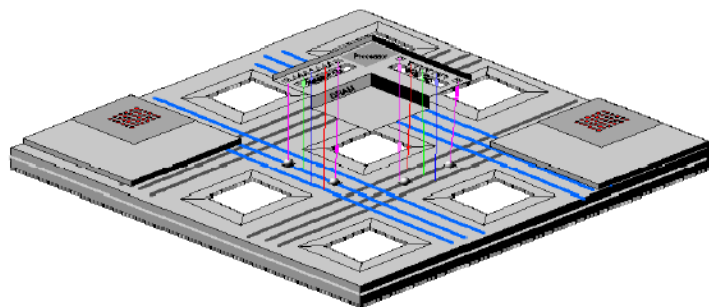


Configurable Optical Interconnect

- * *Same end device requirements*
- * *The fabric can be a static AWG or a tunable cross-bar switch*
- * *No nominal $1/N$ loss*
- * *WDM in the fabric not at the ends*



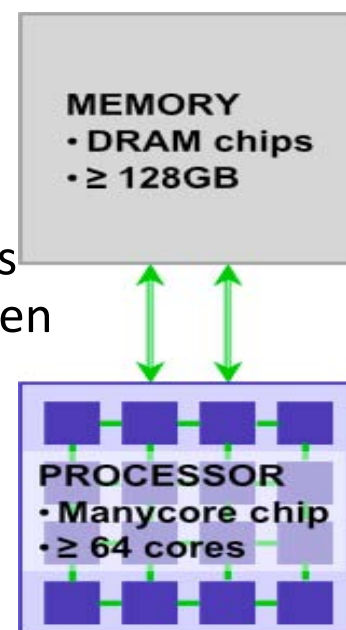
Moving the Vision On-Chip !



The DARPA UNIC Program: Ultraperformance Nanophotonic Intrachip Communications

SUN Microsystems: Macrochip design providing 10 TB/s bisection bandwidth for 64 cores providing 10 TFLOPS

MIT Lincoln Lab: Optimization of optical communication networks among cores, and between cores and memory

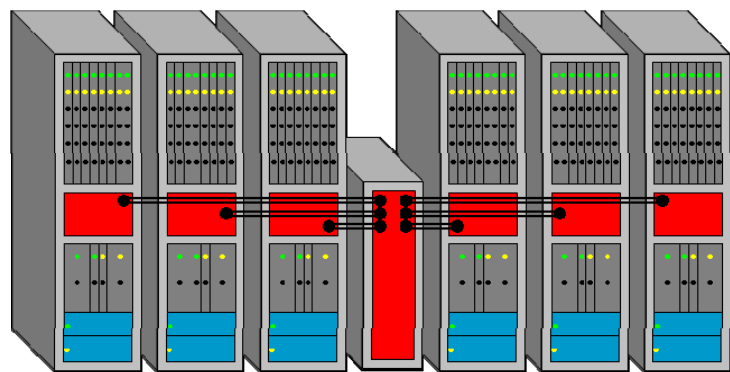


Two Talks:

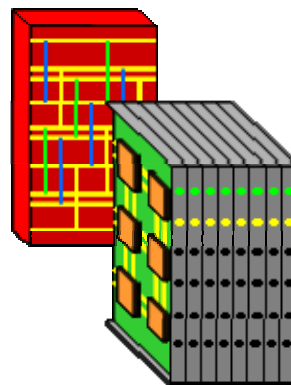
- **Ashok Krishnamoorthy (SUN)** – Intrachip Photonic Communications Networks with Seamless Off-chip Communications: Vision for the Future
- **Jeremy Kepner (MIT/LL)** – Photonically-enabled Optimized Embedded Microprocessors, Shared Memory Optimizing Multicore Cooperation



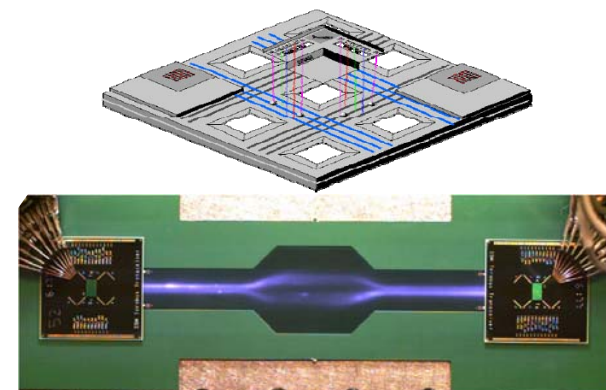
Cooperative Systems of Various Orders of Magnitudes Benefiting from WDM Optical Networking



Intra- / Inter-Rack



Inter-Cards or Boards



Intra- / Inter-Chip

- Of course, the very same devices and components do not work at all scales of the vision
- But the same basic ideas and architectures promise higher performance (capacity and flexibility) at a reduced cost, size and power for all scales of the vision
- Much more work is needed at all scales to realize this vision of multi-terabit-per-second cooperative microsystems

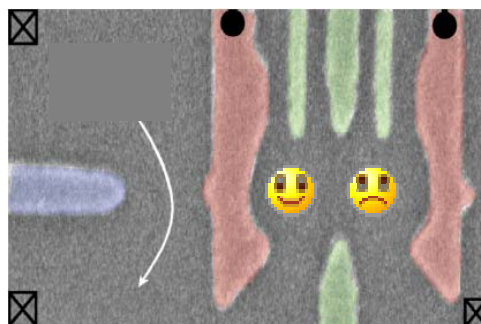


Cooperative Microsystems at a Quantum Scale



Here, the subsystems are quantum states, e.g., electron spin states, photon polarization states, atomic states, etc., and the interconnect is quantum entanglement, *"the spooky action at a distance"*

Entanglement of electron spins in quantum dots defined by gate voltages



Two Talks:

- **Charles Marcus (Harvard) – Cooperative Quantum Microsystems**
- **Charles Bennett (IBM) – The Promise of Quantum Key Distribution**

Today, scientists have succeeded in realizing secure Quantum Key Distribution (QKD) over ~100-km free-space or fiber-optic links using the **BB84 Protocol** conceived by **Bennett and Brassard** in 1984

The holy grail of QKD is to extend the distance to continental scale, using entanglement-based **"quantum repeaters"**



Part of the vision in this sub-session is related to the **DARPA QuEST Program**



And finally for something completely different !



A Talk by:

- **Joe Pancrazio (NIH) – on “Prosthetics, Interconnects, Neuro-Photonics”**

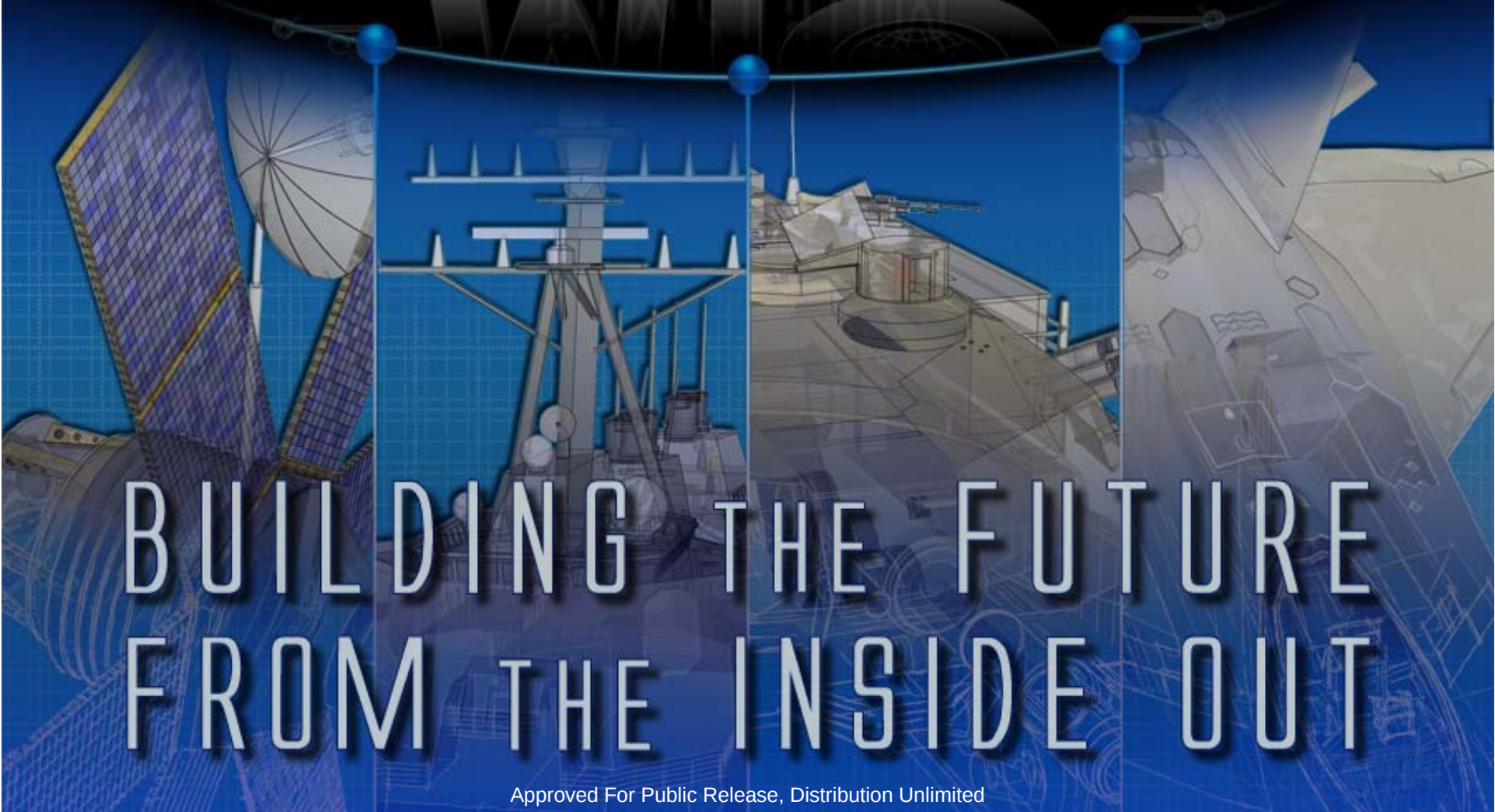
Note that ***Interconnects*** is a common theme, other than that, it is a completely different story

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MTO SYMPOSIUM

The logo for the Microsystems Technology Office (MTO) Symposium. It features the letters 'MTO' in a large, bold, metallic font. A globe with the word 'DARPA' on it is integrated into the 'O'. Circuit traces extend from the 'M' and 'O'. Below 'MTO' is the word 'SYMPOSIUM' in a smaller, white, sans-serif font. The entire logo is set against a dark background with a reflection effect below it.

BUILDING THE FUTURE
FROM THE INSIDE OUT

The background of the poster is a collage of various technological and infrastructure elements. On the left, there's a large satellite dish and a solar panel array. In the center, a complex antenna structure is visible. On the right, there's a detailed view of a ship's deck with various equipment. The entire background is overlaid with a blue grid pattern and a network of lines and nodes, suggesting a global or interconnected theme.

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