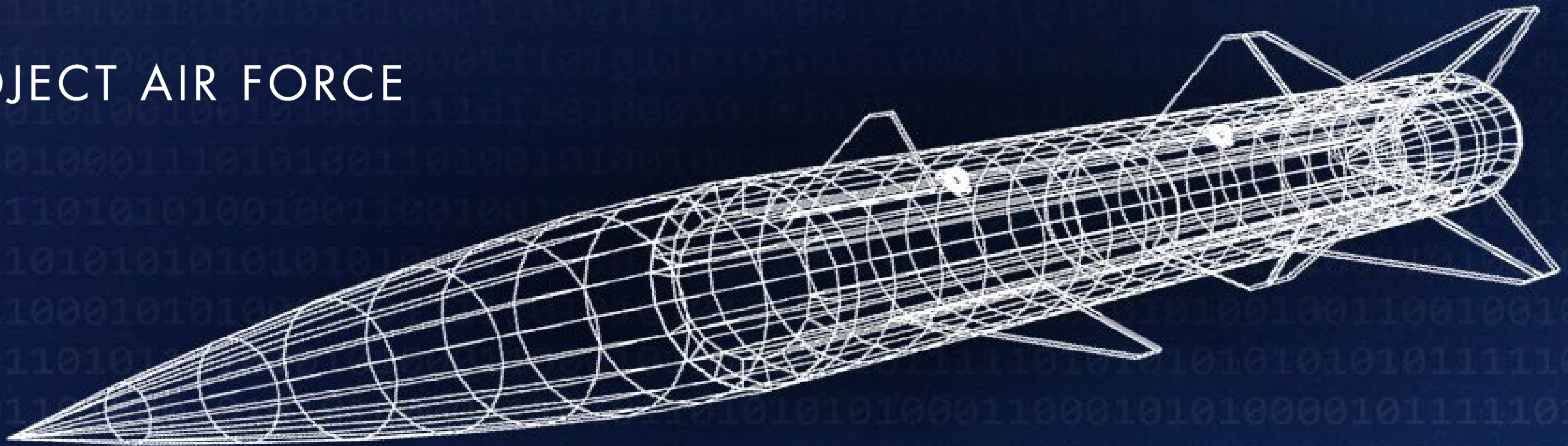
RAND PROJECT AIR FORCE



A Preliminary Assessment of Digital Engineering Implications on Weapon System Costs

ICEAA Conference Brief

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Today's discussion will cover several topics

- Review project goals and objectives
- Characterize digital engineering in theory and practice
- Provide insight into costs that might be impacted by digital engineering
- Identify areas in need of additional research/attention

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This presentation is based on work performed by RAND Project Air Force (PAF)

- Work was sponsored by Air Force Cost Analysis Agency (AFCAA) and focused on digital engineering (DE) from the cost estimator's perspective
- Multi-disciplinary team included:
  - Principal Investigators: Tom Light, Obaid Younossi
  - Brittany Clayton, Peter Whitehead, Jon Wong, Spencer Pfeifer, Bonnie Triezenberg
- Research conducted between June 2020 – June 2021
  - Rapidly evolving area of study
  - Potential for follow-on work to be completed
- Research questions included:
  - What does DE mean to DAF (and DoD) weapon system programs?
  - How are defense programs implementing DE?
  - Which cost elements will be impacted over the system's lifecycle?

Our research methodology included collecting and reviewing information and data from relevant literature and experts in the field

Literature review of available sources

- Research applicable examples
- Categorize DE into major concepts
- Investigate government and industry roles in DE
- Explore policies affecting the implementation of DE

Discussions with key experts

- Conduct discussions with several key players
  - DE Thought Leaders
  - Program Offices
  - Cost analysts
- Explore program-specific documentation and data of DE pathfinder programs

Document observations and lessons learned

- Isolate WBS elements most likely affected by DE
- Identify potential areas for investment and cost savings
- Summarize observations and lessons learned in final report

Most cost estimators will need to account for some level of DE implementation as defense programs move toward a more digital environment

- Defense programs across military services are implementing DE to some extent
- DE implementation has the potential to impact cost analysis tasks
  - Consideration of DE strategies during analyses of alternatives (AoA)
  - Development of system's lifecycle cost estimate
  - Impact on cost benefit analyses for trade-off studies
  - Influence on confidence level during uncertainty analyses

Audience Challenge:
How would you address DE in your cost estimate?
What additional research needs to be done to successfully incorporate DE cost impacts?

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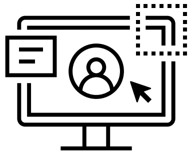
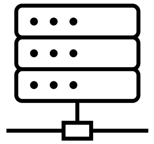
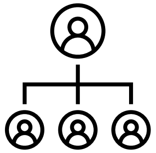
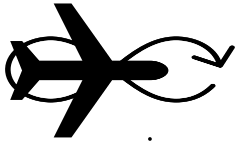
DoD's Digital Engineering Strategy provides a useful starting point for our research

DoD defines digital engineering as "an integrated digital approach that uses authoritative sources of system data and models as a continuum across disciplines to support lifecycle activities from concept through disposal." (DoD Digital Engineering Strategy (2018), p. 2)

Integrated digital approach →  Digital products developed (where possible) that "talk" to each other

Authoritative sources of data and models →  One "authoritative source of truth" for program information

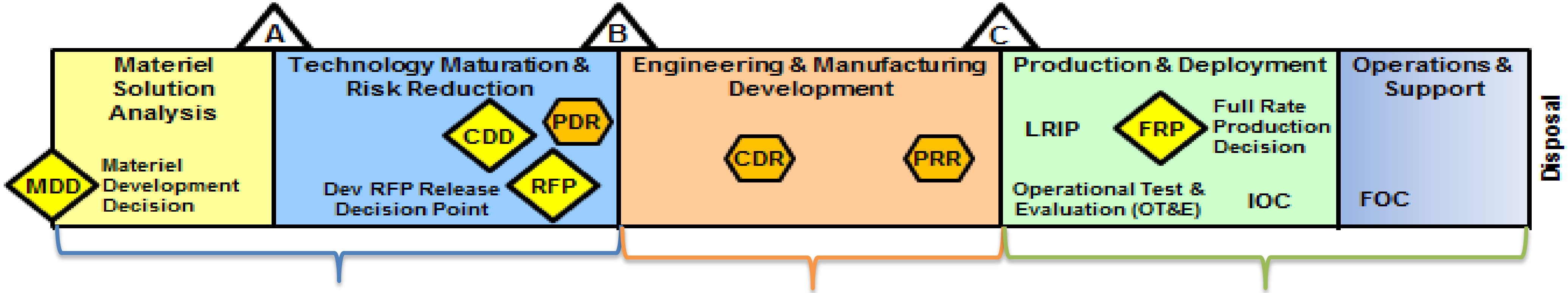
Across disciplines →  Leveraged by all program stakeholders

Support lifecycle activities →  From program initiation through disposal of the system

DAF is pursuing DE implementation, among other similar initiatives

- Policies require DE implementation
  – AFI 63-101/20-101: “The PM utilizes Digital Engineering … to the maximum extent practical.”
- Development of new offices and roles dedicated to the advancement of DE
- Digital initiatives are part of broader efforts to increase speed at which capabilities are developed to meet warfighter needs
  – All aspects of weapon systems are becoming more software-intensive and connected
  – Acquisition is becoming more digitized
- “Digital trinity”
  – Open architecture
  – Agile software development
  – Digital engineering

There exist many examples of DE activities that could be pursued through the weapon system lifecycle



- ❑ Establish model-based links between mission capability and system capability during AoA
- ❑ Use modeling to define requirements and acquisition strategy
- ❑ Develop model-centric RFP/source selection/acquisition processes
- ❑ Define data/model requirements that prime must share with government via SysML
- ❑ Develop data/model validation and verification steps
- ❑ Negotiate contract terms for digital deliverables (e.g., data, models, and IP)

- ❑ Establishes in-house DE capabilities and expertise
- ❑ Contractor digitally shares weapon system design models, data, and IP with government
- ❑ Government engages more intensely with contractor to reduce design, development, and verification costs and make tradeoffs
- ❑ Streamline technical review, data reporting, verification and validation, and test and evaluation processes
- ❑ Transition to model-based deliverables

- ❑ Maintain and update data, models, design and manufacturing information and make accessible to stakeholders
- ❑ Use models to inform cost and schedule trades and during the operational testing phase
- ❑ Reflect deployment plans in program models
- ❑ Leverage data/models in the pursuit of predictive maintenance
- ❑ Use models to identify and evaluate future enhancement and technology refresh opportunities

DE differs across programs, in both definition and implementation

- In practice, we found that no single program was undertaking all of these activities
  - Experts had varying definitions for DE
  - Programs implementing DE in very different ways
- Some of this was dictated by the program's life cycle phase, enthusiasm by program leadership, expertise within the program office, and other considerations

Program A *(TMRR)*

- High-fidelity digital models employed, in hopes to achieve several things
  - ➢Support faster deployment times
  - ➢Support smaller batches of iteratively-upgraded platforms
  - ➢Trouble shoot design, assembly
  - ➢Identify issues in maintenance before physical system exists

Program B *(EMD)*

- Training simulators designed using digital approaches
  - ➢Model-based engineering
  - ➢3D design tools

Program C *(EMD)*

- SysML-based models used to inform program decisions such as acquisition requirements prior to source selection
- Government reference architecture developed to capture, store, link, and use relevant design data
- Digital twin created for every command-and-control element

In literature published in 2020, SAF/AQ Leadership believed DE would yield benefits in many areas

	Purported System Benefits	Purported Portfolio Benefits
Cost	• More accurate requirements help avoid cost overruns • Iterate designs digitally at minimal cost • Move down cost improvement curve faster	• Commodifies design and process to allow faster cycle and more competition • More development cycles, resulting in less operating and maintenance spending
Schedule	• Gets to a better design faster • More efficient development process	• Allows acquisition system to regain enough speed to support more frequent program starts
Performance	• Enables earlier, more accurate identification of requirements and design • Enables open architecture approach that leads to better enhancements over time • Allows for the creation of designs so complex that they cannot be developed without DE	• Guides portfolio development with greater accuracy in iteration on requirements, maintaining industrial base.

Benefits, however, are based on several key assumptions:

DoD/DAF Execution

- DE enables acquisition speed that overmatches the enemy
- Government can implement at the scale necessary to reap benefits (especially portfolio)
- O&M savings at least partially offset RDT&E and Procurement cost increases

Industry

- Manufacturing base can design and manufacture to required tolerances
- Industry is willing to restructure to play in a more commodified marketplace

Nature of DE

- Digital Twin: Models are accurate and robust enough to *replace/reduce* physical prototyping
- Single "Authoritative Source of Truth;" right people have access to right information across disciplines

Based on review of W. Roper "*There is No Spoon: The New Digital Acquisition Reality,*" *Department of the Air Force,* October 7, 2020.

There is plenty of anecdotal evidence of DE and model-based system engineering (MBSE) benefits but almost no verifiable empirical evidence

- **Physical prototyping:** Digital models may reduce (but not eliminate) the need for costly physical prototypes
- **Test and evaluation:** Digital testing may reduce the iterations of physical testing needed, or refine the testing and evaluation plan more precisely, resulting in less spending on test and evaluation
- **Manufacturing:** DE efforts may allow greater optimization of requirements and manufacturing designs
- **Weapon system maintenance and modifications:** The development of digital twins and systematic collection of other weapon system data may aid in future maintenance and modification efforts
- **Weapon system capability**: Digital development enables more (spiral) development efforts, smaller total quantities, and greater diversity of fielded systems
- **IP Ownership to government**: Government will own technical baseline of more weapon systems; this will enable DoD/DAF to share and leverage models and data across acquisition, sustainment, and modernization efforts

A review of 847 papers found that all but 2 papers report perceived benefits of DE/MBSE without evidence and most noted benefits unrelated to cost (Henderson and Salado, 2021)

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Discussions with cost analysts confirm there are challenges with incorporating DE into the cost estimate

- Uncertainty around what DE means to DAF
  - Familiarity with digital engineering concept varies
  - Challenges with isolating DE from other initiatives (agile acquisition, open system architecture, etc.)
  - Differences in how DE is being implemented by programs
- Confusion around the roles and responsibilities of government vs. contractors
- Concerns that classification levels will create a challenge with integration and sharing of data/models
- Enterprise efforts to support DE (training opportunities, investments in computing power, etc.) are still being defined and not mature
- Limited evidence and no methodology to support adjusting program cost estimates to account for DE

Discussions from varying perspectives hint at possible broader insights that have implications for cost analysis

Theme	Emerging Observations	Potential cost analysis implications
Definition	Defining DE may depend on what benefits are expected to be gained	Cost analysts may need to **work closely** w/ program management to understand DE benefits being sought, tailor cost analysis approach to match
Implementation	New paradigms needed to relate digital thread to cost analysis areas of interest	Cost analysis may wish to **deliberately take different approaches** to leveraging digital threads across different pathfinder programs to accelerate experience and learning
Benefits	Increased weapon system performance may be the most feasible DE benefit gained	Cost analysts may need to adopt **a cost avoidance mindset** at program level to better understand, contextualize DE investments and potential benefits while looking to measure cost savings at enterprise level
Measurement	Measuring investment costs will be possible; returns may be indirect, difficult to measure	Estimates for discrete investments (training courses, software licenses, etc.) will likely be straightforward. **Quantifying downstream or enterprise effects will be more difficult**
Stakeholder relationships	Renewed DoD systems engineering role will have program management impacts	Renewed DoD systems engineering role may have cost implications as DoD **regenerates expertise**

There are specific investments cost analysts should consider, though not all will need to be accounted for in every estimate

IT Infrastructure Required to Support DE	DE Standards, Data, Architectures
• Computing hardware • Storage • Bandwidth and connectivity • Cloud based services	• Acquisition Reference Model and Government Reference Architecture • Establishment of model access and traceability criteria • Configuration management of models/data • Data rights/IP
Models and Tools	**Workforce**
• New digital deliverables (e.g., digital twins) • Software (e.g., PLM, CAD, analysis, simulation, MBSE packages) • Labor required to develop and tailor digital models and tools to weapon system	• Workforce development plan • Workforce training on applicable software • MBSE-ready skills • New/additional staff positions • Labor required to develop and tailor digital models and tools to weapon system

Discussions with cost analysts and program office staff suggest these costs not likely to map neatly to specific WBS elements

The Air Force has identified six main areas of focus to accomplish DE

- **IT Infrastructure**
  - Bandwidth
  - Computing Power
  - Storage
- **Models & Tools**
  - Software Down-select
  - Software Licenses
- **Standards, Data & Architecture**
  - Data Rights
  - Establish GRA for program
  - Integration of Digital Twin
- **Lifecycle Strategies & Processes**
  - Maintenance of Software Access/Updates
- **Policy & Guidance**
  - DE Guidebook Updates
  - Specific Guidance on DE Activities
- **Workforce & Culture**
  - General DE Training
  - Software-specific Training
  - Recruitment of educated Systems Engineers

Examples of investments from SME discussions:

- 3 – 4 FTE dedicated to DevSecOps
- 1 FTE dedicated to the transport layer including hardware, interconnectivity, connection to cloud, etc.
- 3 FTEs working on MBSE models and the GRA
- Program office training on TeamCenter software package expected to take 18 – 24 months
- Purchase of TeamCenter seat licenses for program office and external stakeholders
- Purchase of PlatformONE licenses, software updates, associated tools, etc.
- Hiring contractors / FFRDCs / UARCs to help with implementation

Responsible Organization:

Air Force Enterprise

Program Office

Generated based on six Lines of Effort identified in Major General Bill Cooley's presentation entitled "DE Industry Day Briefing" (September 2020).

Our team developed a framework for considering the costs and benefits of DE

Investments

- Upfront costs required to create enablers of DE

Enablers

- Lines of Effort (LOEs) outlined in DE Guidebook

Activities

- Tasks to be performed by the program office and contractors to implement DE

DE Environment

- Depending on activities performed, some level of DE will be achieved

Benefits

Cost and non-cost benefits of DE

Cost estimate aims to account for the bookends

Order of planning ←

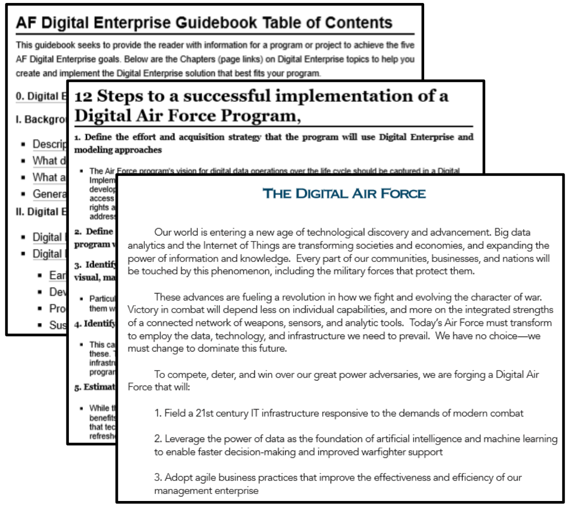
Order of execution →

A generalized process can be repeated across multiple programs working to include DE into the cost estimate

1. FAMILIARIZE

Familiarize the cost team with the concepts and goals of digital engineering.

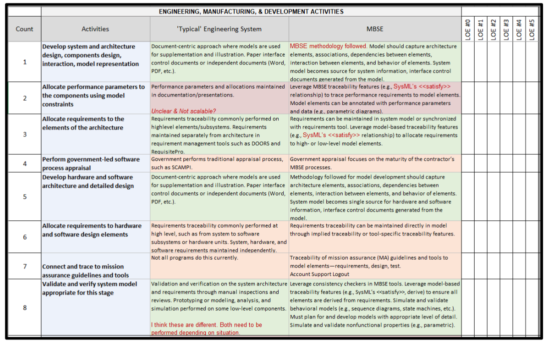
- ❑ Digital Engineering Guidebook
- ❑ The Digital Air Force white paper



2. COORDINATE

Coordinate with your program office to understand how they are implementing digital engineering.

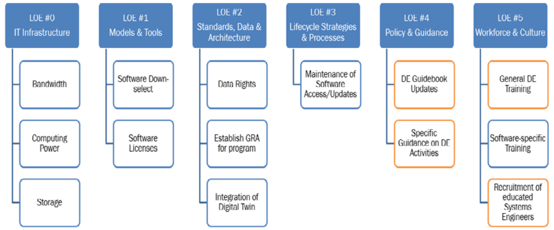
- ❑ Understand which activities the program office is undertaking through each phase of the acquisition lifecycle.
- ❑ Use the mapping of activities to enablers to identify focus / goals of digital engineering specific to your program.



3. IDENTIFY

Identify specific investments and benefits applicable to your estimate.

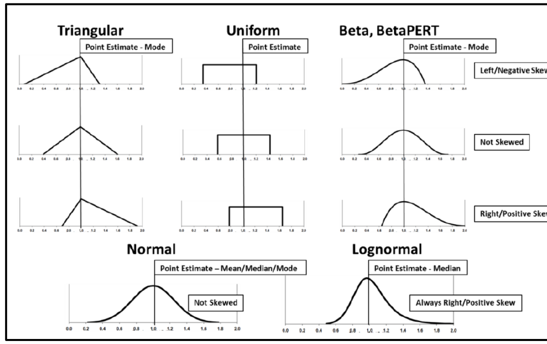
- ❑ Investments line up with enablers
- ❑ Map investment to your WBS



4. INCORPORATE

Incorporate investments and benefits into the estimate using a generally accepted approach.

- ❑ Adjust the point estimate
- ❑ Incorporate into uncertainty analysis
- ❑ Develop sensitivity analysis



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To reflect DE in future cost estimates, we recommend AFCAA develop a repository of DE program information

- Ensure any DE-specific requirements such as AFLCMC's 23 DE Features are identified and scoped, e.g.:
  - Integrated Digital Environment
  - Government Reference Model
  - Digital Twin
  - Data Rights / Intellectual Property
  - Model Integration
- Collect relevant cost information on DE-specific requirements
  - May require adoption of alternative cost accounting approaches
- Validate savings from DE-specific activities as program matures
  - Impact on Cost Improvement Curve
- Integrate with SAF/AQR's DE Maturity Metrics
  - Metrics capture a program's level of DE engagement in the areas of infrastructure, modeling and analysis, process and policies, and workforce and culture

To realize the benefits in systems acquisition, we recommend DAF continue to progress the DE agenda

- Continue to invest in DE infrastructure and in workforce with DE skills/competencies
- Develop a plan to assess DE programs' efforts, claims, and impacts
  - Evaluation plan will likely need to be tailored to each program’s DE approach and should be developed in consultation with stakeholders
- Investigate how DE efforts are impacting suppliers and the supply chains
- Integrate core systems engineering practice with digital engineering concepts and initiative

Digital engineering terminology

Terminology	Definition
Digital Artifact	An artifact produced within, or generated from, the digital engineering ecosystem. These artifacts provide data for alternative views to visualize, communicate, and deliver data, information, and knowledge to stakeholders.
Digital Engineering	An integrated digital approach that uses authoritative sources of systems' data and models as a continuum across disciplines to support lifecycle activities from concept through disposal.
Digital Engineering Ecosystem	The interconnected infrastructure, environment, and methodology (process, methods, and tools) used to store, access, analyze, and visualize evolving systems' data and models to address the needs of the stakeholders.
Digital System Model	A digital representation of a defense system, generated by all stakeholders that integrates the authoritative technical data and associated artifacts which define all aspects of the system for the specific activities throughout the system lifecycle.
Digital Thread	An extensible, configurable and component enterprise-level analytical framework that seamlessly expedites the controlled interplay of authoritative technical data, software, information, and knowledge in the enterprise data-information-knowledge systems, based on the Digital System Model template, to inform decision makers throughout a system's life cycle by providing the capability to access, integrate and transform disparate data into actionable information.
Digital Twin	An integrated multiphysics, multiscale, probabilistic simulation of an as-built system, enabled by Digital Thread, that uses the best available models, sensor information, and input data to mirror and predict activities/performance over the life of its corresponding physical twin.
Government Reference Architecture (GRA)	The Government Reference Architecture has features, properties, and characteristics satisfying, as far as possible, the problem or opportunity expressed by a set of system requirements (traceable to mission/business and stakeholder requirements) and life cycle concepts (e.g., operational, support) and are implementable through technologies (e.g., mechanics, electronics, hydraulics, software, services, procedures, human activity) developed and represented in the system model developed by prime contractor.

Note: Definitions draw from one program office's DE Implementation Plan

DoD's Digital Engineering Strategy provides a useful starting point for our research

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Traditional activities	DE activities
Document based	Model based
Static Delivery	Dynamic Model
Event Based Review	Continuous review
Product Based	Service Based
Rigid Process	Adaptive Process
Static Warehoused Data	Dynamic Discoverable Data
Well defined stakeholder	Enabled dynamic collaboration
OEM-driven, proprietary architectures and interfaces	Gov't driven architectures and interface standards