IT2EC 2022
London
28 April 2022

My Digital Sibling

Andy Fawkes
FIMechE

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The Enduring Task

Reality ⟷ **Representation of Reality**

eg.

Weather

Engineering

Entertainment

Health

…

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Outline

- Some Personal Context
- Digital Twin Challenges
- Digital Twin Fidelity

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Some Personal Context

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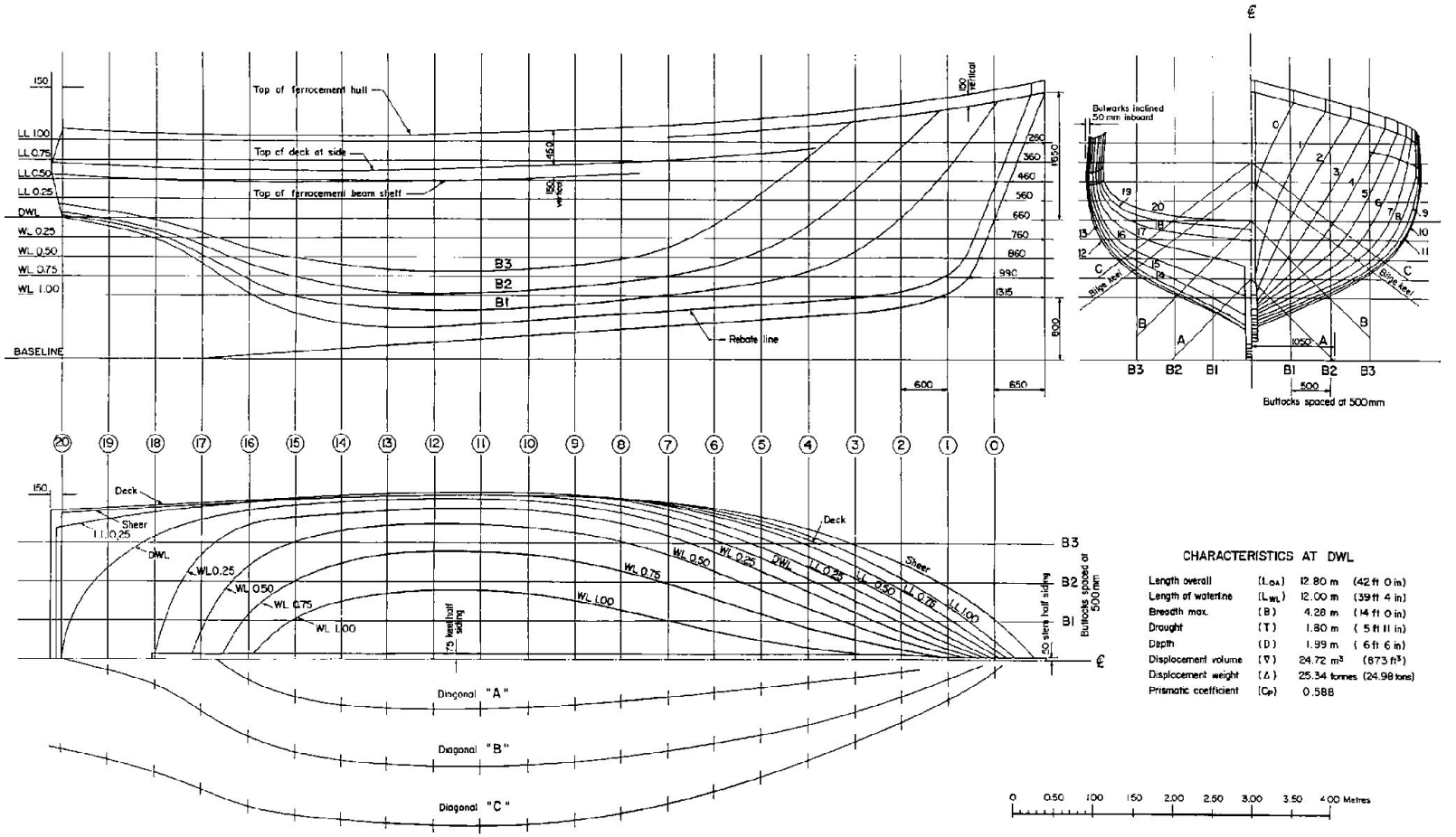
Early Career



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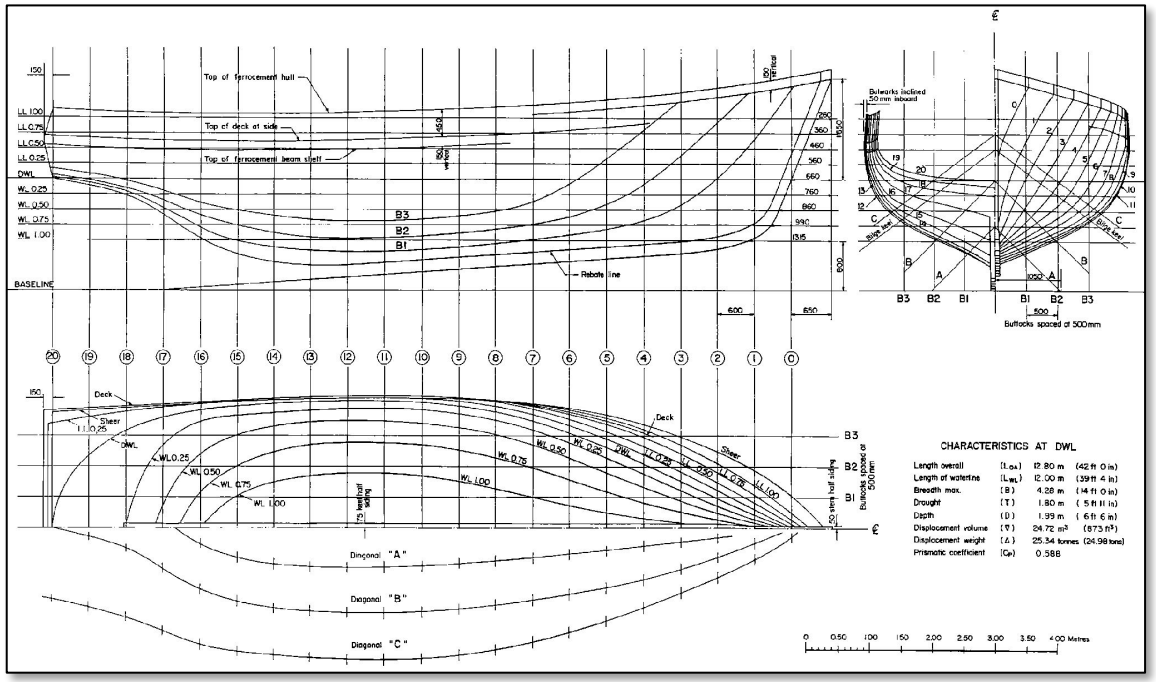
Paper-Based Design



Not Easily:-

Changeable
Discoverable
Repeatable
Storage(able)
Transferable

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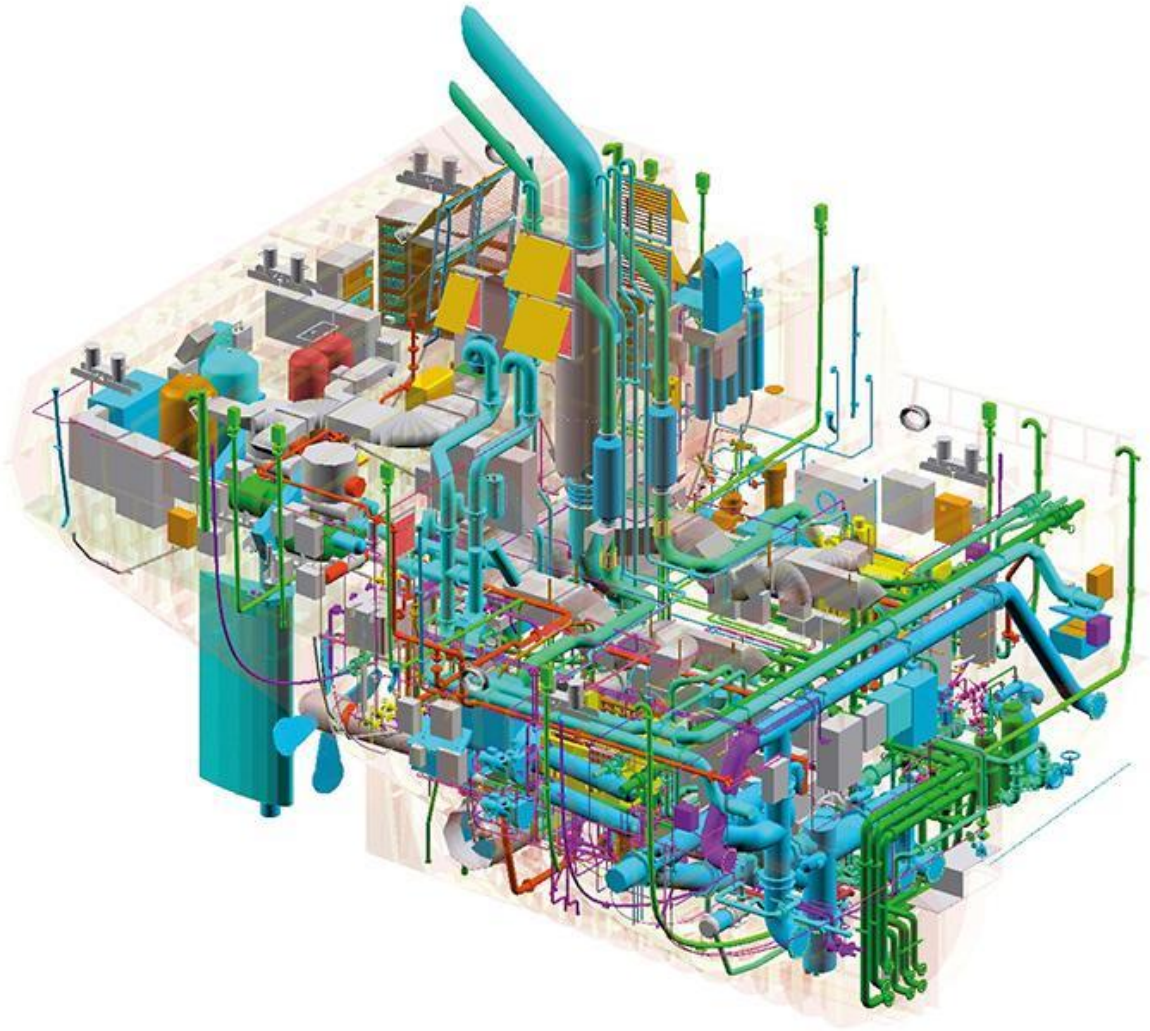
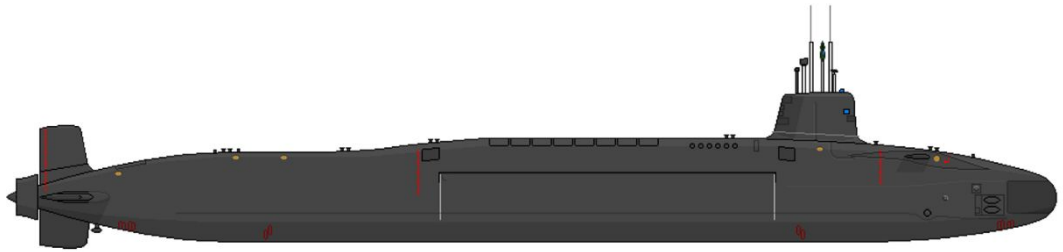
Physical 3D Models





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Disposal

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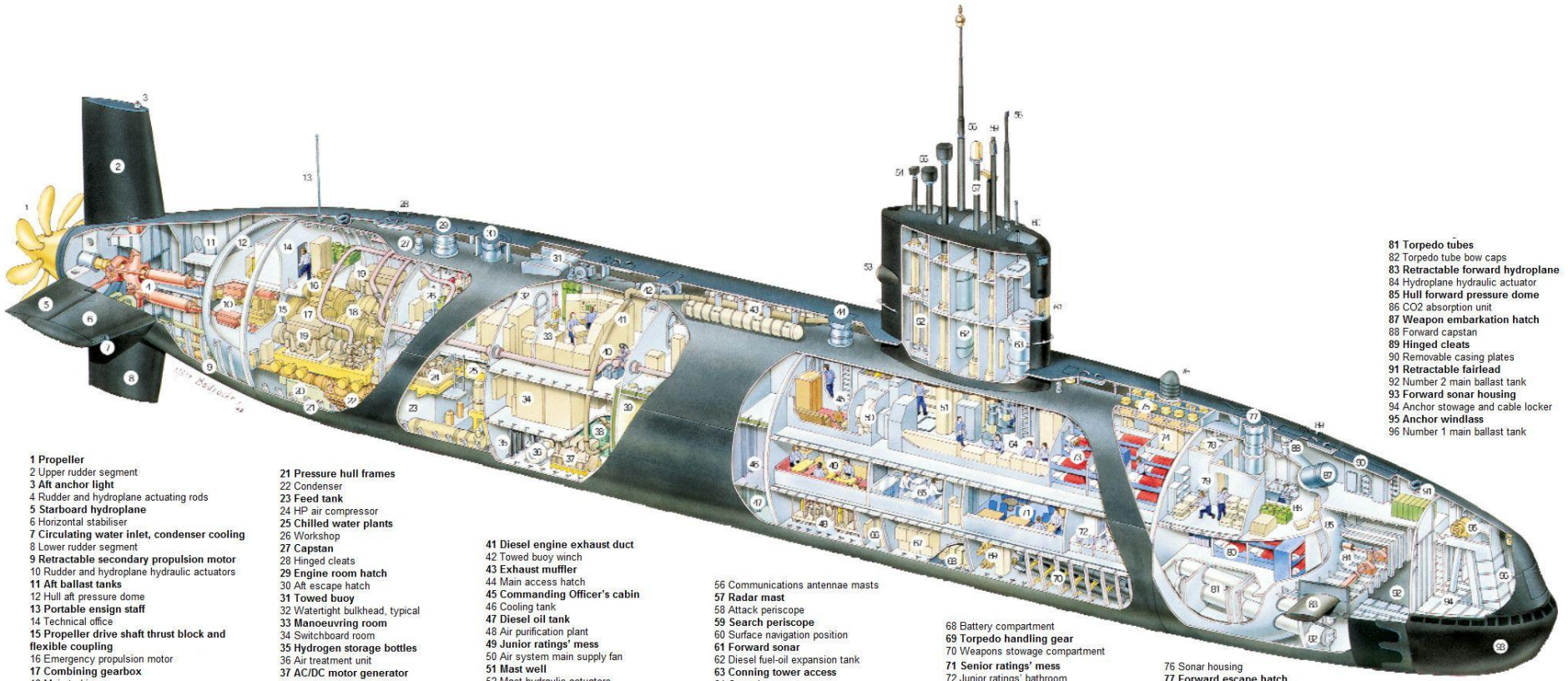
Training & Operational Analysis



1 Propeller
2 Upper rudder segment
3 Aft anchor light
4 Rudder and hydroplane actuating rods
5 Starboard hydroplane
6 Horizontal stabiliser
7 Circulating water inlet, condenser cooling
8 Lower rudder segment
9 Retractable secondary propulsion motor
10 Rudder and hydroplane hydraulic actuators
11 Aft ballast tanks
12 Hull aft pressure dome
13 Portable ensign staff
14 Technical office
15 Propeller drive shaft thrust block and flexible coupling
16 Emergency propulsion motor
17 Combining gearbox
18 Main turbines
19 Turbo generators
20 Lubricating oil tank

21 Pressure hull frames
22 Condenser
23 Feed tank
24 HP air compressor
25 Chilled water plants
26 Workshop
27 Capstan
28 Hinged cleats
29 Engine room hatch
30 Aft escape hatch
31 Towed buoy
32 Watertight bulkhead, typical
33 Manoeuvring room
34 Switchboard room
35 Hydrogen storage bottles
36 Air treatment unit
37 AC/DC motor generator
38 Diesel generators
39 Reactor compartment
40 Main steam valve

41 Diesel engine exhaust duct
42 Towed buoy winch
43 Exhaust muffler
44 Main access hatch
45 Commanding Officer's cabin
46 Cooling tank
47 Diesel oil tank
48 Air purification plant
49 Junior ratings' mess
50 Air system main supply fan
51 Mast well
52 Mast hydraulic actuators
53 Aft sonar
54 Diesel exhaust
55 Snort induction mast, fresh air

56 Communications antennae masts
57 Radar mast
58 Attack periscope
59 Search periscope
60 Surface navigation position
61 Forward sonar
62 Diesel fuel-oil expansion tank
63 Conning tower access
64 Control room
65 Galley
66 Garbage ejector compartment
67 Data distribution racks

68 Battery compartment
69 Torpedo handling gear
70 Weapons stowage compartment
71 Senior ratings' mess
72 Junior ratings' bathroom
73 Senior ratings' bunks
74 Sonar equipment room
75 Hull sonar glands

76 Sonar housing
77 Forward escape hatch
78 Coxswain's stores
79 Dry provisions store
80 Junior ratings' bunks

81 Torpedo tubes
82 Torpedo tube bow caps
83 Retractable forward hydroplane
84 Hydroplane hydraulic actuator
85 Hull forward pressure dome
86 CO2 absorption unit
87 Weapon embarkation hatch
88 Forward capstan
89 Hinged cleats
90 Removable casing plates
91 Retractable fairlead
92 Number 2 main ballast tank
93 Forward sonar housing
94 Anchor stowage and cable locker
95 Anchor windlass
96 Number 1 main ballast tank

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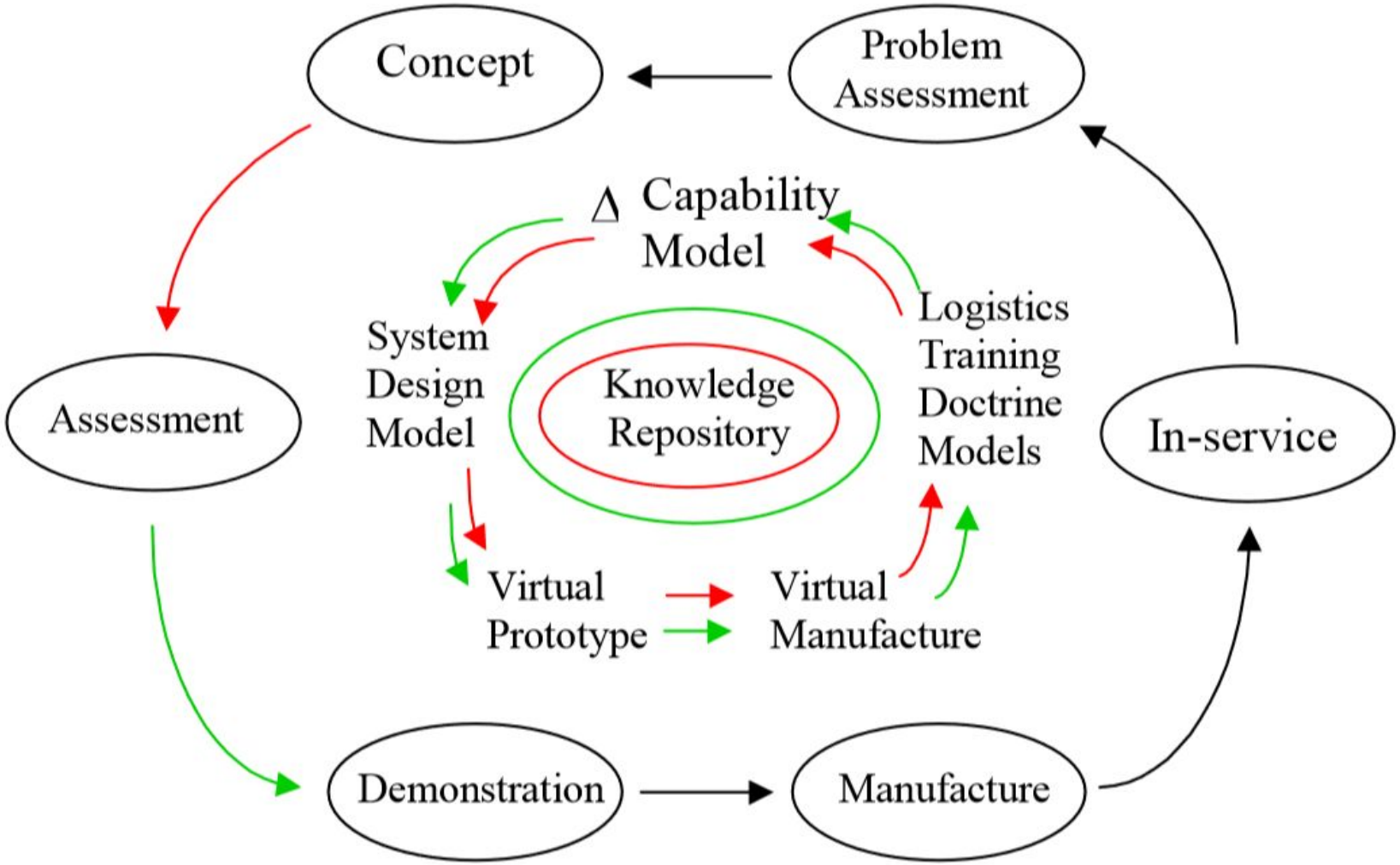
Temporal Context – The UK "SeBA Wheel"



Synthetic Environment Based Acquisition

Simulation Based Acquisition: The Ground Truth, 2002
Lt Cdr Monty Long RN, Mr Steve Gale Dstl

THINK

ITEC 2018

ITEC Advanced Engineering Conference
Stuttgart, Germany - 16 May 2018

Simulation Based Acquisition - Has its Time Come?

Andy Fawkes

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"Digital Thread" & "Digital Twin"

Credit: Boeing

AVIATION WEEK NETWORK

AVIATIONWEEK & SPACE TECHNOLOGY Step INSIDE the next evolution

USAF Selects Lead Programs For 'Digital Twin' Initiative

Aviation Week & Space Technology
Graham Warwick
Jan 26, 2015

Digital system models are seen as key to regaining understanding of complex systems

Threading the Needle

Over the years, the U.S. Air Force has come to rely more and more on industry for its technical understanding of the systems it acquires. To reverse that process and bring costs and risks more under its control, the service is experimenting with creating and carrying digital system models through the entire life cycle of a program.

The acquisition process now being piloted has two key elements: the "digital thread," a model of the system that begins at conceptualization and evolves through its life to retirement; and the "digital twin," a model of the system as built, including any manufacturing discrepancies, that is used to support the system in service.

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Human Digital Twin

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VRAI Wins Royal Air Force Data & Simulation Project

DECEMBER 10, 2020

Data driven VR simulation company VRAI has won a Defence and Security Accelerator (DASA) contract focused on improving the RAF's ability to measure and predict pilot performance using a combination of VR & data analytics technology.

The company based in Gateshead's Proto Centre, and RAFX based in the local airbase RAF Leeming, was awarded the £348k funding to work with the Royal Air Force (RAF) to help codify and assess 'airmanship' in pilots. VRAI creates data driven VR simulation training for high hazard environments, with clients including leading organisations such as the IAG in Heathrow Airport, the United Nations in Somalia, and other European militaries.

AINonline BIZAV AIR TRANSPORT DEFENSE ROTORCRAFT SUBSCRIBE

50 YEARS OF AIN

BUSINESS AVIATION

SMU and CAE Apply Biometrics to Flight Training

by Stuart "Kipp" Lau - March 1, 2022, 9:07 AM

Biometrics offer a compelling look at how pilots react when the workload increases, and research by SMU and CAE reveals some interesting results about real-time determination of pilot performance and capabilities when pilots are under stress.

Researchers at Southern Methodist University (SMU) are developing an innovative approach that combines biometrics with machine learning techniques to reshape the future of flight training. The goal is to measure physical reactions of the pilot to provide—in real-time—a more objective and automated determination of performance to make flight training more personalized, effective, and efficient. Flight training programs have historically relied on subjective observations and post-flight analysis from an instructor to determine proficiency and mastery of a maneuver.

Teamed with simulator manufacturer and training provider CAE, researchers from SMU's AT&T Center for Virtualization are entering the fourth year of a project to develop and test methods to measure situational awareness and cognitive load sensing using biometrics and machine learning. The goal is to capture how pilots react to various scenarios in a flight simulator.

Machine learning is the study of algorithms that can improve automatically through experience and gathering

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Metaverse!

"The metaverse enables us to embed computing into the real world and to embed the real world into computing ..."

Satya Nadella, CEO Microsoft, Microsoft Ignite Nov 2021

SISO Simulation Interoperability Standards Organization
"Simulation Interoperability & Reuse through Standards"

The Military's Metaverse

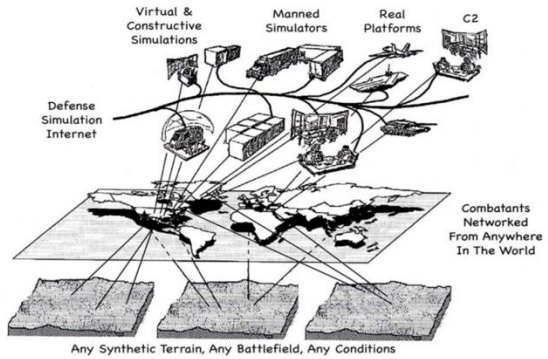
SIM-2021-Presentation-22 (SIMbrief)

Andy Fawkes, Thinke Company, UK

2021 SIMposium 21-22 September 2021

A Military Metaverse?

"Persistent secure networked interoperable live, virtual and constructive simulations, synchronized with multi-domain operational systems and enterprise-wide digital twins of equipments, platforms, infrastructure and personnel and the wider human and natural world."



SIMNET's 1980s Vision
Jack Thorpe PhD

2021 SIMposium SISO

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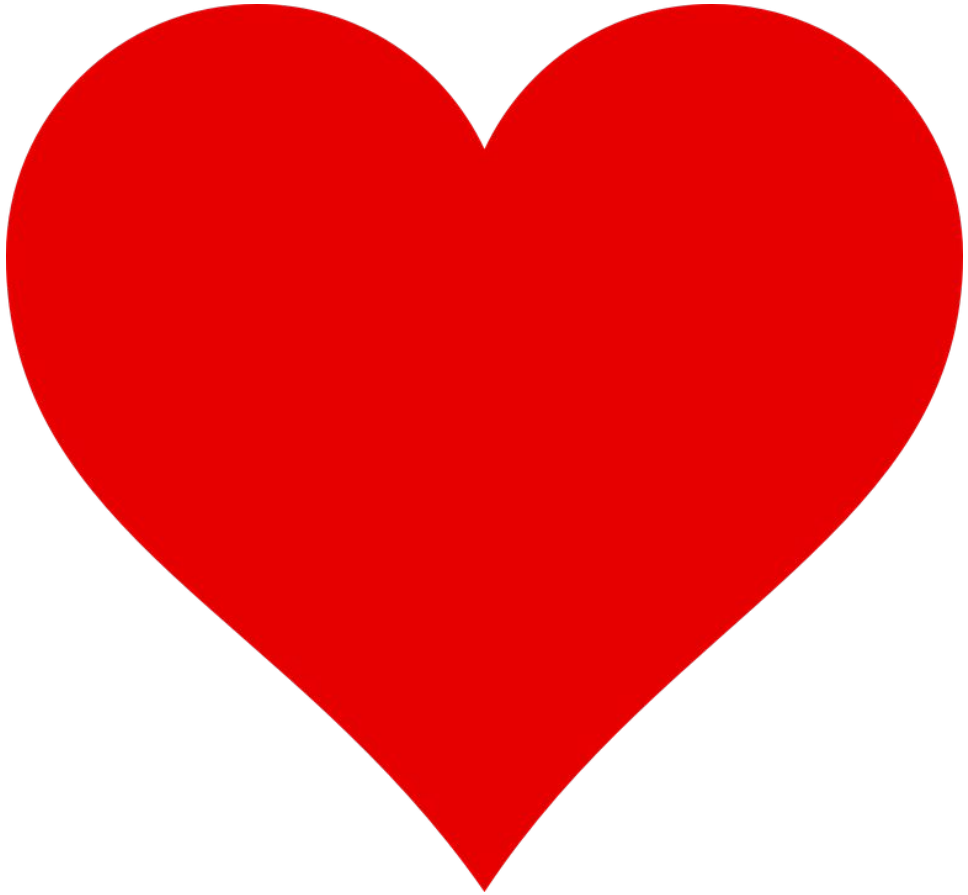
Digital Twins are Great



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Digital Twin Challenges

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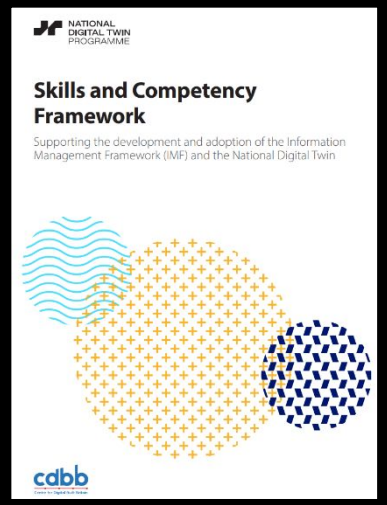
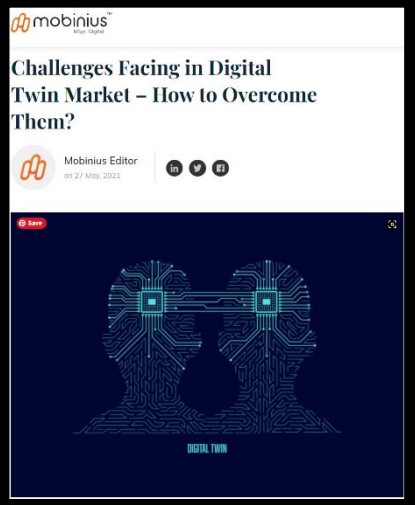
Challenges - Commercial, Cultural and Technological





- Commercial (eg. multi-stakeholder ecosystems)
- Cultural (eg. complex cross-silo collaboration)
- Technical
  - Accurate Capturing of Physical Properties Digital twin technology should be able to model both simple objects and complex systems by accurately capturing their physical properties.
  - Project Collaboration Digital twin technology should be able to collaborate and connect with other digital twins in a variety of contexts.
  - Automatic Updates in Real-Time It should be self-informed of its functionality in real-time and change or alter when required.
  - Conflict Detection and Resolving It should be able to detect and react to changes in a real-time environment.
  - Interaction with Digital and Physical Entities It can communicate with other virtual objects or digital twins in an immersive manner.

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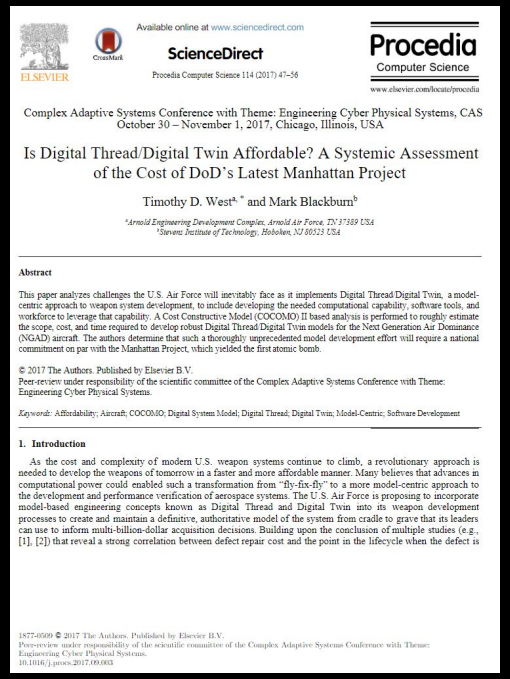
Challenges - Cost #1



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Complex Adaptive Systems Conference with Theme: Engineering Cyber Physical Systems, CAS October 30 – November 1, 2017, Chicago, Illinois, USA

Is Digital Thread/Digital Twin Affordable? A Systemic Assessment of the Cost of DoD's Latest Manhattan Project

Timothy D. West[a,*] and Mark Blackburn[b]

[a]Arnold Engineering Development Complex, Arnold Air Force, TN 37389 USA
[b]Stevens Institute of Technology, Hoboken, NJ 80523 USA

Abstract

This paper analyzes challenges the U.S. Air Force will inevitably face as it implements Digital Thread/Digital Twin, a model-centric approach to weapon system development, to include developing the needed computational capability, software tools, and workforce to leverage that capability. A Cost Constructive Model (COCOMO) II based analysis is performed to roughly estimate the scope, cost, and time required to develop robust Digital Thread/Digital Twin models for the Next Generation Air Dominance (NGAD) aircraft. The authors determine that such a thoroughly unprecedented model development effort will require a national commitment on par with the Manhattan Project, which yielded the first atomic bomb.

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Peer-review under responsibility of the scientific committee of the Complex Adaptive Systems Conference with Theme: Engineering Cyber Physical Systems.

Keywords: Affordability; Aircraft; COCOMO; Digital System Model; Digital Thread; Digital Twin; Model-Centric; Software Development

1. Introduction

As the cost and complexity of modern U.S. weapon systems continue to climb, a revolutionary approach is needed to develop the weapons of tomorrow in a faster and more affordable manner. Many believes that advances in computational power could enabled such a transformation from "fly-fix-fly" to a more model-centric approach to the development and performance verification of aerospace systems. The U.S. Air Force is proposing to incorporate model-based engineering concepts known as Digital Thread and Digital Twin into its weapon development processes to create and maintain a definitive, authoritative model of the system from cradle to grave that its leaders can use to inform multi-billion-dollar acquisition decisions. Building upon the conclusion of multiple studies (e.g., [1], [2]) that reveal a strong correlation between defect repair cost and the point in the lifecycle when the defect is

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Peer-review under responsibility of the scientific committee of the Complex Adaptive Systems Conference with Theme: Engineering Cyber Physical Systems.
10.1016/j.procs.2017.09.003

USAF Next Generation (6th) Air Dominance (NGAD) aircraft

- **USAF Arnold Engineering Development Complex research estimated the cost to develop and sustain a robust digital thread/digital twin models would be in excess of $1 trillion.**
- **These very high costs were attributed to the required computational power required, software costs, and the training of the workforce.**

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Challenges - Cost #2

PERSPECTIVE
https://doi.org/10.1038/s43588-021-00023-0

nature computational science

Check for updates

The digital revolution of Earth-system science

Peter Bauer[1]✉, Peter D. Dueben[1], Torsten Hoefler[2], Tiago Quintino[3], Thomas C. Schulthess[4] and Nils P. Wedi[1]

Computational science is crucial for delivering reliable weather and climate predictions. However, despite decades of high-performance computing experience, there is serious concern about the sustainability of this application in the post-Moore/Dennard era. Here, we discuss the present limitations in the field and propose the design of a novel infrastructure that is scalable and more adaptable to future, yet unknown computing architectures.

The human impact on greenhouse gas concentrations in the atmosphere and the effects on the climate system have been documented and explained by a vast resource of scientific publications, and the conclusion—that anthropogenic greenhouse gas emissions need to be drastically reduced within a few decades to avoid a climate catastrophe—is accepted by more than 97% of the Earth-system science community today[1]. The pressure to provide skillful predictions of extremes in a changing climate, for example, the number and intensity of tropical cyclones and the likelihood of heatwaves and drought co-occurrence, is particularly high because the present-day impact of natural hazards at a global level is staggering. In the period 1998–2017, over 1 million fatalities and several trillion dollars in economic loss have occurred[2]. The years between 2010 and 2019 have been the costliest decade on record with the economic damage reaching US$2.98 trillion—US$1.19 trillion higher than 2000–2009[3]. Both extreme weather and the potential failure to act on climate change rank as the leading risks combining maximum likelihood and impact for our future[4].

These losses do not invalidate the steady progress achieved in weather prediction over the past decades, that is, the combined result of improved observing systems, a better understanding of the relevant physical processes occurring and interacting in the Earth system and the exponential growth of general-purpose computing technology performance at nearly constant cost[5]. However, continuing at this pace is being questioned right now for two major reasons. First, the apparent effects of climate change on our environment—in particular on the frequency of occurrence and the intensity of environmental extremes—require urgent political response and much faster progress in delivering skillful predictions of future change[6,7]. Earth-system models need more than steady progress and make a leap to very high resolution, a more realistic representation of processes at all scales and their interaction between atmosphere, ocean, cryosphere, land surfaces and the biosphere. This leap will inevitably translate into a leap in our computational and data handling capacity needs. Second, the explosion of data challenges[8] and the demise of the 'laws' of Dennard and Moore[5] require a rethinking of the way we approach Earth-system modeling and high-performance computing (HPC) at extreme scales. These laws have been driving the development of microchips for decades. Dennard scaling states that shrinking feature sizes of transistors also decreases their power consumption such that the frequency could be increased from processor generation to the next while the heat dissipation per chip area remained approximately constant. Dennard scaling ended nearly 15 years ago and led to the 'multicore crisis' and the advent of commodity parallel processing. Moore's law drove the economics of computing by stating that every 18 months, the number of transistors on a chip would double at approximately equal cost. However, the cost per transistor starts to grow with the latest chip generations, indicating an end of this law. Therefore, in order to increase the performance while keeping the cost constant, transistors need to be used more efficiently.

In this Perspective, we will present potential solutions to adapt our current algorithmic framework to best exploit what new digital technologies have to offer, thus paving the way to address the aforementioned challenges. In addition, we will propose the concept of a generic, scalable and performant prediction system architecture that allows advancement of our weather and climate prediction capabilities to the required levels. Powerful machine learning tools can accelerate progress in nearly all parts of this concept.

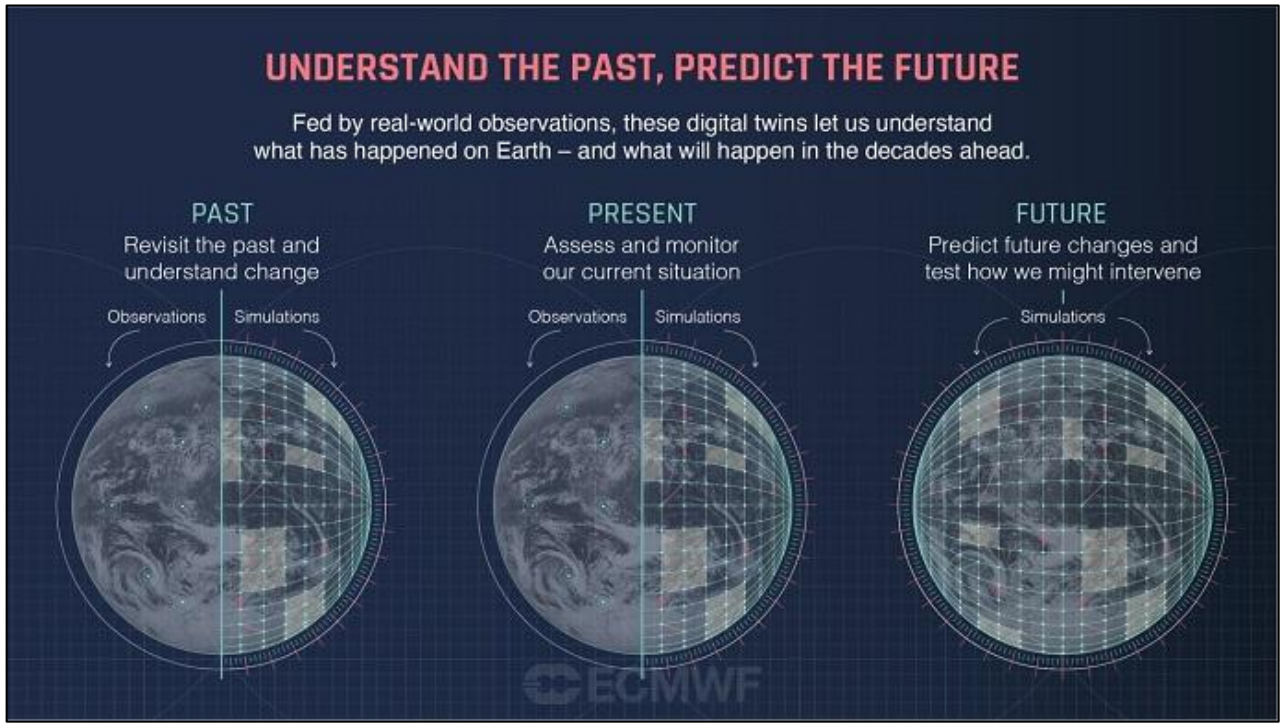
The perfect application for extreme computing

Weather prediction has been a pioneering application of numerical computer simulations since John von Neumann's 'Meteorology Project' in the late 1940s[9–11]. Much has been achieved since then and today's operational global predictions are completed within an hour for models with about 10 million grid points, 100 vertical layers and 10 prognostic variables, initialized using 100 million observations per day. These calculations run on hundreds of nodes of general-purpose central processing units (CPU) offered by vendors in the US, Asia and Europe. The need to run simulation ensembles for predicting both state and uncertainty[12–14] multiplies both compute and data burden—but has proven hugely beneficial for decision-making[15].

Figure 1 illustrates the elements of an operational weather prediction workflow, in which steps 2–4 are very compute- (peta-flops) and data- (100 terabytes per day) intensive. Weather simulations are different from climate simulations as they are run in burst mode at given times per day while climate predictions are run in steady-production mode to complete multi-decadal, centennial and millennial projections of the climate.

Given the computational constraints, weather and climate models have diverged in the past decades: climate models need to represent closed and stable energy, water and constituent cycles at the expense of small-scale process detail; weather models, on the other hand, need this level of detail for locally accurate forecasts, but choose to exclude those Earth-system processes that are less relevant for weather on day-to-season time scales. For example, the accurate description of water-cycle processes is highly relevant for

[1]Research Department, ECMWF, Reading, UK. [2]Computer Science Department, ETH Zürich, Zürich, Switzerland. [3]Forecast Department, ECMWF, Reading, UK. [4]CSCS, ETH Zürich, Lugano, Switzerland. ✉e-mail: peter.bauer@ecmwf.int



“Destination Earth”

- A joint project between the number of European scientific organisations to develop a highly accurate digital twin of Earth.
- Researchers have estimated it will require a supercomputer with 20,000 graphics processors consuming 20MW of power.

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Challenges
-
Terminology
-
Digital Twin

Wikipedia

“a virtual representation that serves as the real-time digital counterpart of a physical object or process”.

Arup

“the combination of a computational model and a real-world system, designed to monitor, control and optimise its functionality. Through data and feedback, both simulated and real, a digital twin can develop capacities for autonomy and to learn from and reason about its environment.”

Wright, Louise & Davidson, Stuart. (2020) - characterised by:

- **a model of the object,**
- **an evolving set of data relating to the object,**
- **a means of dynamically updating or adjusting the model in accordance with the data, and**
- **being associated with an entity that actually exists (a digital twin without a physical twin is a model)**

What is a Digital Twin before the real counterpart is built?

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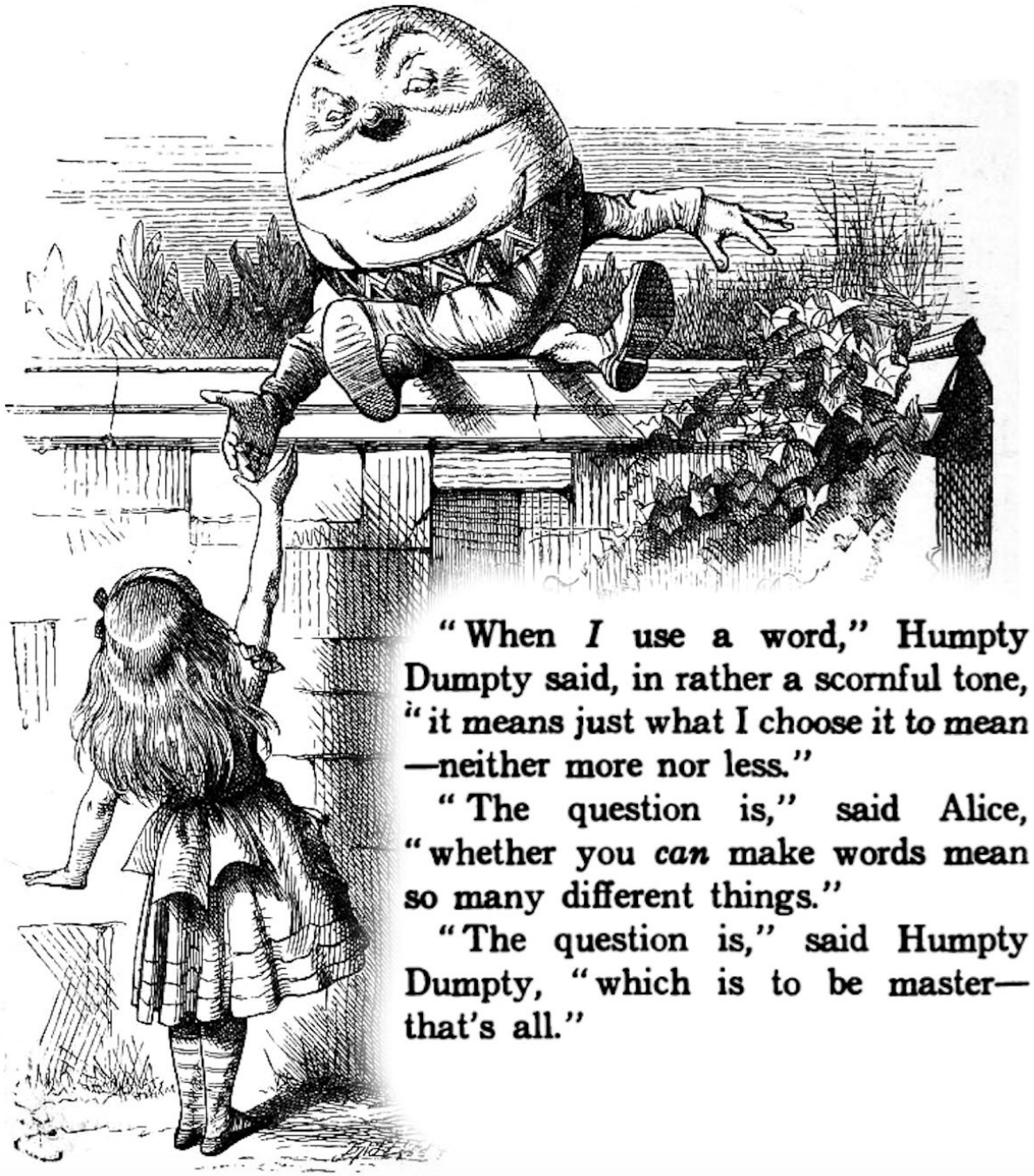
Challenges
-
Terminology
-
Lewis Carroll's Through the Looking Glass



"When *I* use a word," Humpty Dumpty said, in rather a scornful tone, "it means just what I choose it to mean —neither more nor less."

"The question is," said Alice, "whether you *can* make words mean so many different things."

"The question is," said Humpty Dumpty, "which is to be master— that's all."

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Digital Twin Fidelity

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Fidelity

Cambridge Dictionary

“the degree to which a copy of something shows the true character of the original”

Do we always need to have the highest fidelity digital twin models and data?

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The Ages of a Digital Twin?

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IET Digital Twin Maturity Spectrum

Maturity element (Logarithmic scale of complexity & connectedness)	Defining principle	Outline usage
0	Reality Capture	As built survey
1	2D map/system or 3D model	Design/asset optimisation and coordination
2	Connect model to persistent (static) data	Design/asset management
3	Enrich with real-time data (e.g. IoT, sensors)	Operational efficiency
4	Two-way data integration and interaction	Remote and immersive operations
5	Autonomous operations and maintenance	Complete self-governance with total oversight and

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UK CADMID Acquisition Cycle

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Example Mapping Digital Twin Maturity Against Life Cycle

	Concept	Assessment	Demonstration	Manufacture	In-Service	Disposal
Legacy System				2	3	2
New System	1	2	3	4	5	2

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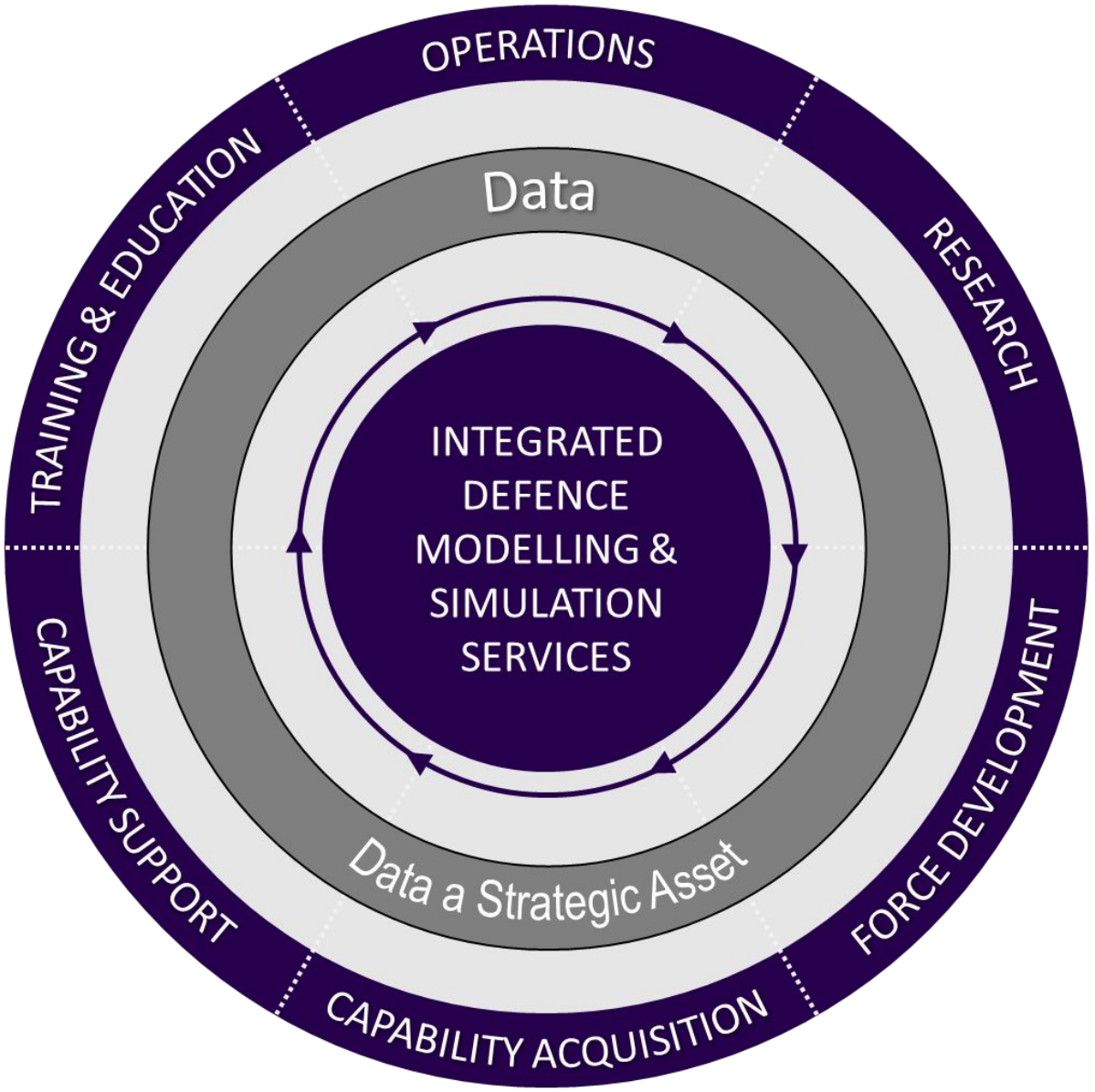
Through-Life Data Management



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UK MoD's Digital Strategy (2021)

- Defence will value Data as a strategic asset
- Data is catalogued, accessible, useable

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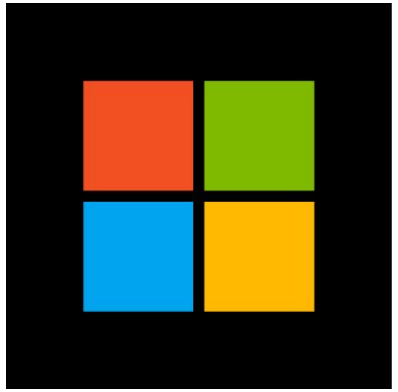
Tools are Already Out There



Microsoft metaverse technology stack

Microsoft Mesh & HoloLens
Enable anyone across the planet to collaborate in mixed reality environments.

Microsoft Power Platform
Empower anyone within your organization to interact with and act on the data flowing through your environment. Build applications, dashboards, and intelligent chatbots that modernize workflows.

Azure AI & Autonomous Systems
Azure AI delivers breakthrough insights into all your data. Microsoft Project Bonsai provides a low-code approach to machine teaching and creating intelligent autonomous systems that learn and improve over time.

Azure Synapse Analytics
A comprehensive set of data services that work together to provide predictive analytics, the ability to analyze data across systems, and the ability to track the historical state of your environment.

Azure Maps
The location of things. Indoor private maps enable you to apply location and routing services to people and things in your private environment while keeping data locked down to your enterprise.

Azure Digital Twins
Simplify the creation of detailed, comprehensive digital models. Support for the Digital Twin Definition Language enables modeling of complex relationships between things and systems in your environment.

Azure IoT
Connect physical assets and run cloud intelligence directly on premises. Sense and monitor anything in your physical environment seamlessly and securely.

The physical world

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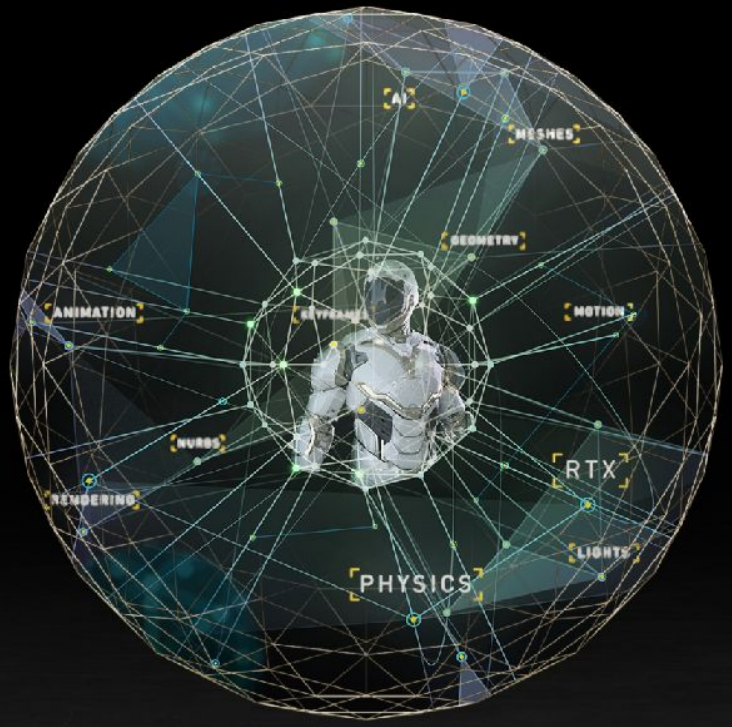
Tools are Already Out There

Collaborators using
their favorite 3d application

Omniverse Nucleus



Portal into Omniverse

AI

Path-Tracing

USD

Materials

Physics

Core Technology

In Summary

- Language can be confusing so it is important not to lose sight of the vision
- Digital Twins do not always need the highest Fidelity to be useful – *an imperfect model through life is better than a perfect model in the moment*
- Data should be treated as a strategic asset across Defence and through the life of projects

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IT2EC 2022
London
28 April 2022

Questions?

Andy Fawkes
andy.fawkes@thinke.co.uk

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