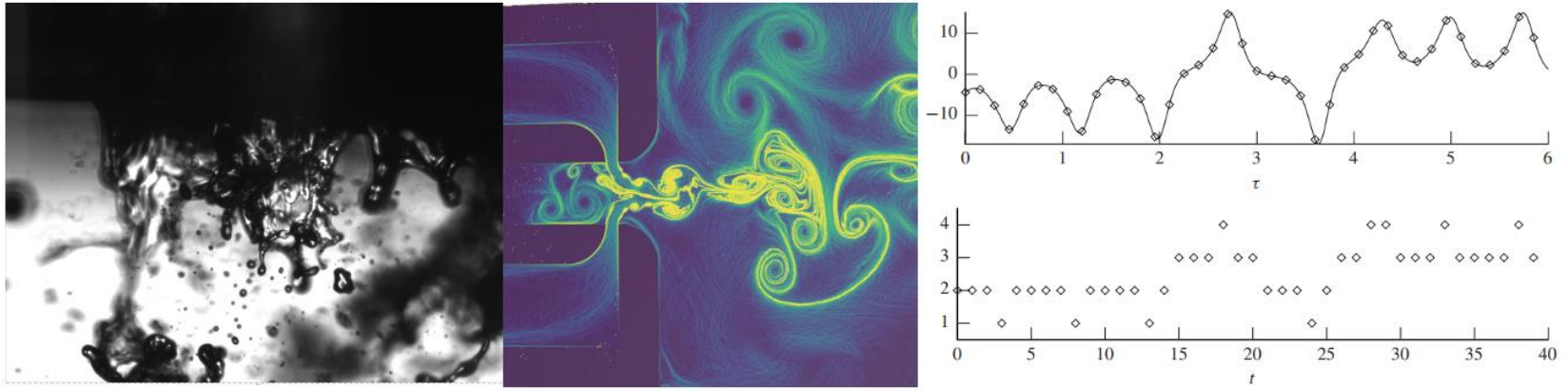
Data Driven Engineering II: Advaced Topics

Introduction to DDE II

Institute of Thermal Turbomachinery
Prof. Dr.-Ing. Hans-Jörg Bauer



Today's Agenda:

1) Data Driven Engineering

2) Content of the lecture & our aim

3) Candidate Projects & work flow

What is “Data Driven Engineering”?

DDE := Data + Model + Artefact

✓ **Data** intensive (driven) **science** is not new

- ❑ Embedded in def. Civilization:= “Book Keeping”
- ❑ Temple records: on taxes, trade goods

- ❑ Astronomy:
- ❑ “Classification” & “Forecasting”

Beer trade ~ 3000 BCE

~ 4000 BCE

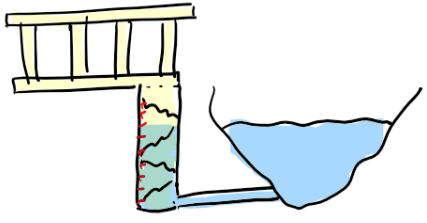
Book of Fixed Stars

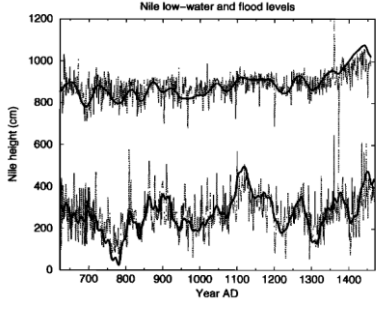
Dunhuang Star Chart

What is “Data Driven Engineering”?

DDE := **Data** + Model + Artefact

- ✓ **Data** intensive (driven) **engineering** is not new
  - ❑ d(Civilization)/dt := “Irrigation”
  - ❑ Ancient Egypt:
  - ❑ Temple records: **Nilometer**
  - ❑ Communicating vessels application
  - ❑ Flow regime prediction: “Auto-regression”

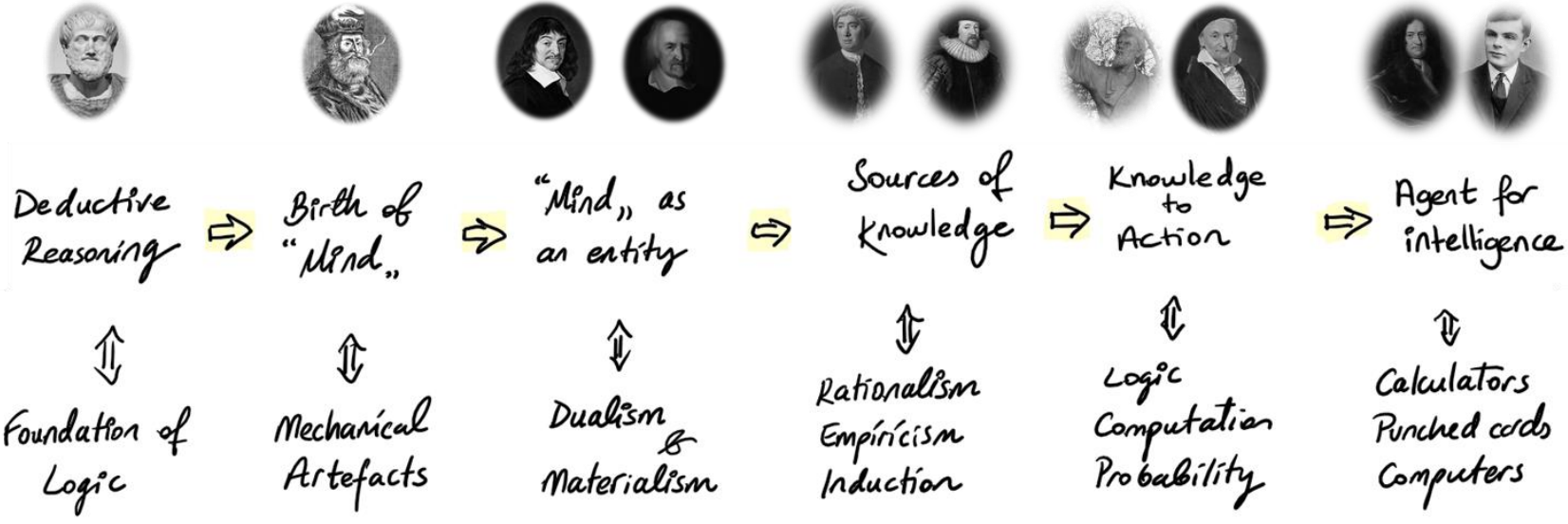




What is “Data Driven Engineering”?

DDE := **Data** + Model + Artefact

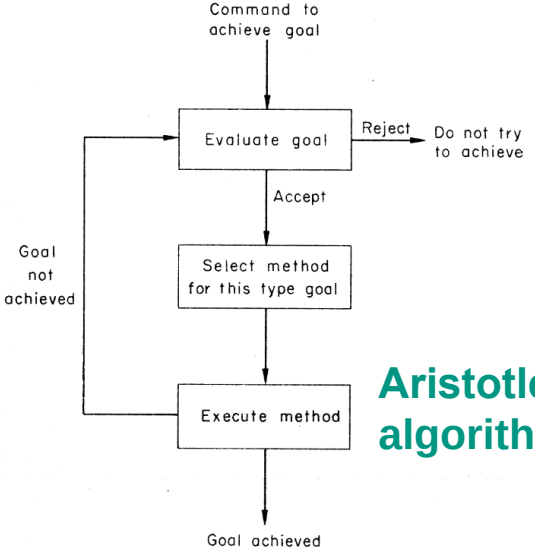
Model = **f**(Data) ➔ 5000+ years of cultivation: “recipes”



Data Driven Engineering

DDE := **Data** + **Model** + Artefact

General Problem Solver (1959)



Aristotle's algorithm

Wearable sensor data and self-reported symptoms for COVID-19 detection (Nature Medicine 2021)

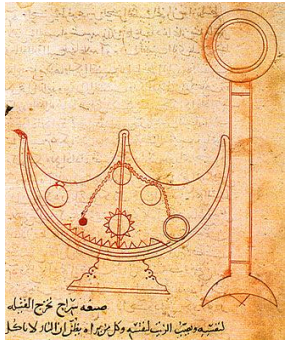
by the authors to understand the information processes that underlie human intellectual, adaptive, and creative abilities.

'An attempt at a new analysis of the mortality caused by smallpox and of the advantages of inoculation to prevent it.'

Daniel Bernoulli, **1766**

What is “Data Driven Engineering”?

DDE := Data + Model + **Artefact**



“Book of Ingenious Devices”
CE 850

memory, feedback control, delays

Lullian Circle ~ 1300s

machine made of paper to combine elements of thinking

Mechanical Calculators

Rechenuhr 1620
Pascaline 1642

What is “Data Driven Engineering”?

DDE := Data + Model + **Artefact**

Hobbes describing **artificial being**:
For what is the heart but a spring; and the nerves, but so many strings; and the joints, but so many wheels. (Leviathan 1651)

Pascal talking about **Pascaline:**
*Arithmetical machine produces effects which **appear nearer to thought** than all the actions of animals. (1642)*

Leibniz discussing the **“automation” of calculation**:
It is beneath the dignity of excellent men to waste their time in calculation when any peasant could do the work just as accurately with the aid of a machine. (1694)

What is “Data Driven Engineering”?

DDE := Data + Model + **Artefact**

Tools for **computations** and **data management**:

knotted strings (BCE 4000)

Software engineering: 500 BCE
Sanskrit grammar ~Turing machine

122 := 1001111

Binary code:
Rishi Pingala ~ 200 BCE

What has changed ?

* ML := Data + Model + Artefact

[~ 200 years] → Accessibility

Literacy in Data Driven Methods

Eg:

3000 BCE

→ Symbol-like language
↓
very difficult to learn
↓
"Rare resource"
[Clerics]

⇒

ΟΔΥΣΣΕΙΑ

Ἄνδρα μοι ἔννεπε, Μοῦσα, πολύτροπον, ὃς μάλα πο
πλάγχθη, ἐπεὶ Τροίης ἱερὸν πτολίεθρον ἔπερσε·
πολλῶν δ' ἀνθρώπων ἴδεν ἄστεα καὶ νόον ἔγνω,
πολλὰ δ' ὅ γ' ἐν πόντῳ πάθεν ἄλγεα ὃν κατὰ θυμόν
ἀρνύμενος ἥν τε ψυχὴν καὶ νόστον ἑταίρων.
ἀλλ' οὐδ' ὣς ἑτάρους ἐρρύσατο, ἱέμενός περ·
αὐτῶν γὰρ σφετέρῃσιν ἀτασθαλίῃσιν ὄλοντο,
νήπιοι, οἳ κατὰ βοῦς Ὑπερίονος Ἠελίοιο
ἤσθιον· αὐτὰρ ὁ τοῖσιν ἀφείλετο νόστιμον ἦμαρ.

Homer's Odyssey

} Democratization of Abstract thinking

What has changed ?

* ML := Data + Model + Artefact

Data:

- ☑ Collect
- ☑ Process
- ☑ Store
- ☑ Access

"in large scale"

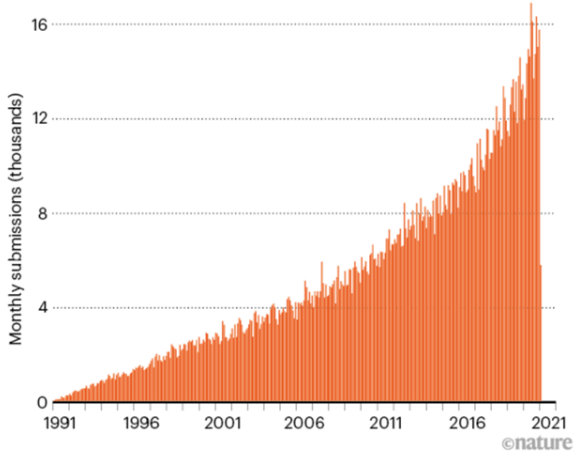
* Sci. Journals → 42,491 (33,119 Eng.)

↳ Scopus ⇒ ~22,000 Journals

⇒ 69 M Core Records

~ 5 paper/min

"Open Access"



Source: arXiv.org

What has changed ?

* ML := Data + Model + Artefact

☑ Accessible high performance ML algorithms & pre/post processing tools + hardware → CPU ✓, GPU ✓, TPU ✓

colab

What is this lecture about ?

Data Driven Engineering : Advanced topics

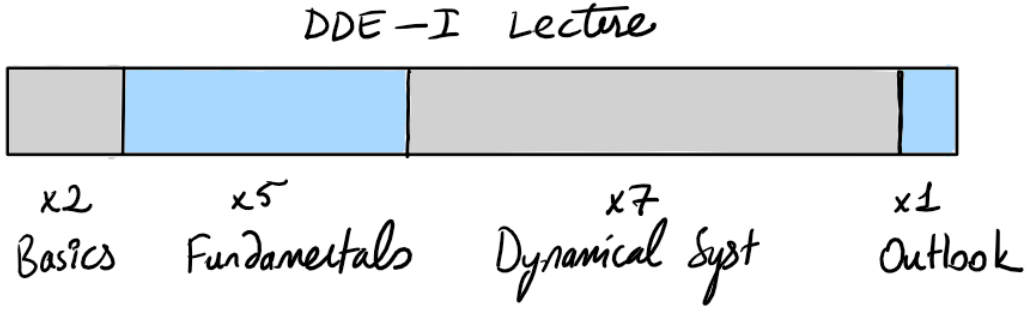
1. Data
   - ↓ Lecture
   - Project
2. Method
   - ↓ Lecture
   - Project
3. Artefact
   - ↓ Lecture
   - Project

i) Beginner
ii) Intermediate
iii) Advanced

} DDE 1
} DDE 2

What is this lecture about ?

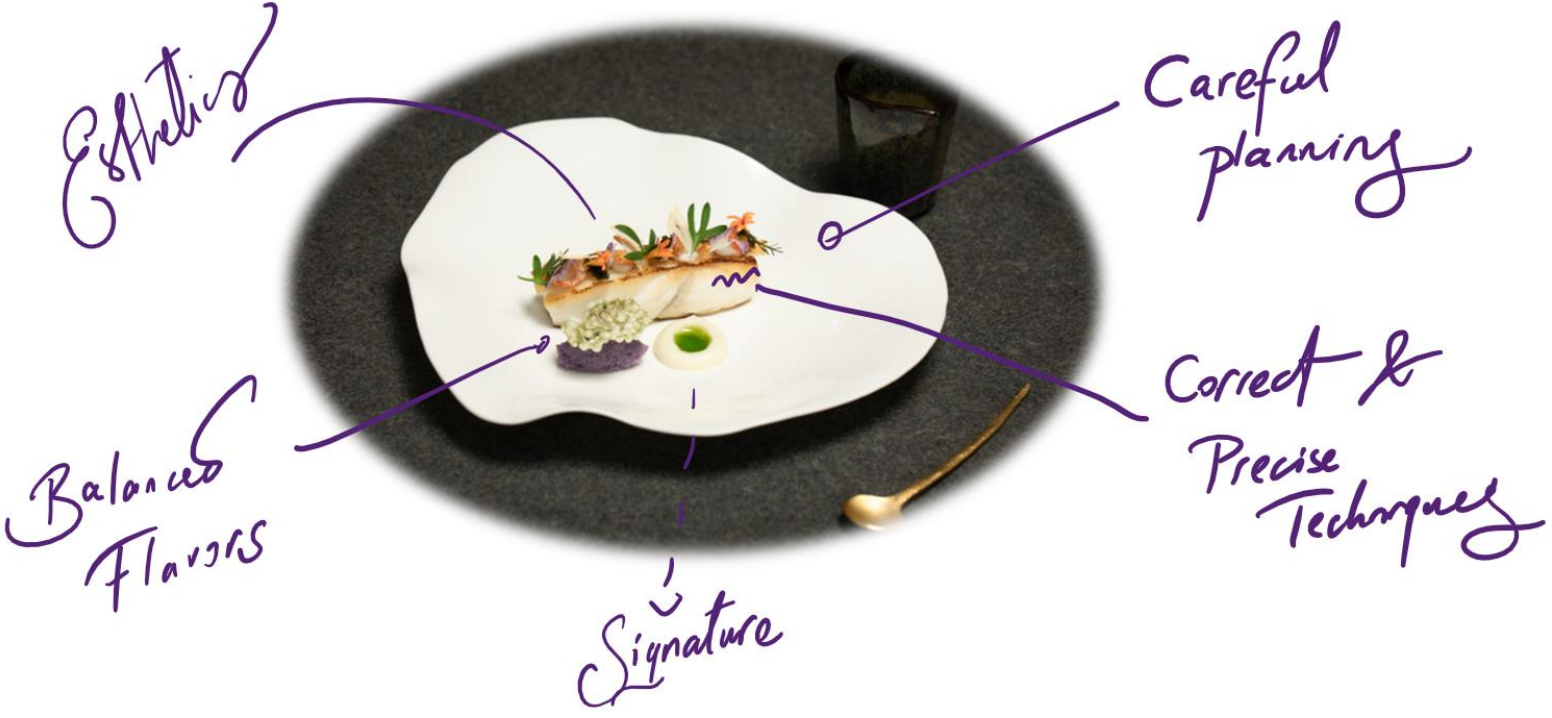
DDE-I



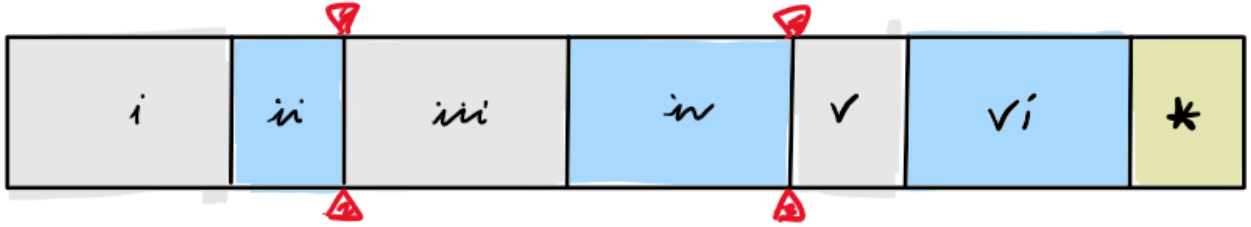
- 6 ML Classes
- 35 model architectures + 11 aux. models
- 10 x 45' Coding Sessions

The Style

DDE II Advanced Topics



What is this lecture about ?



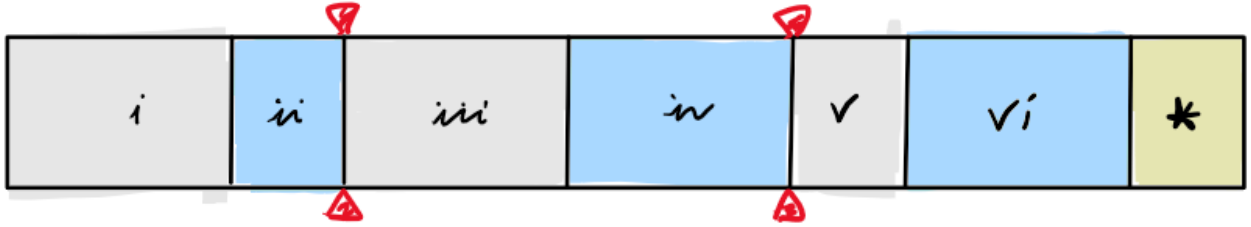
10 lectures.
3 Project sessions

1. Data Driven Image processing

2. DMD

3. Modeling of transport phenomena with NN
   - heat tr.
   - fluid flow
   - mass tr.

What is this lecture about ?



10 lectures.
3 Project sessions

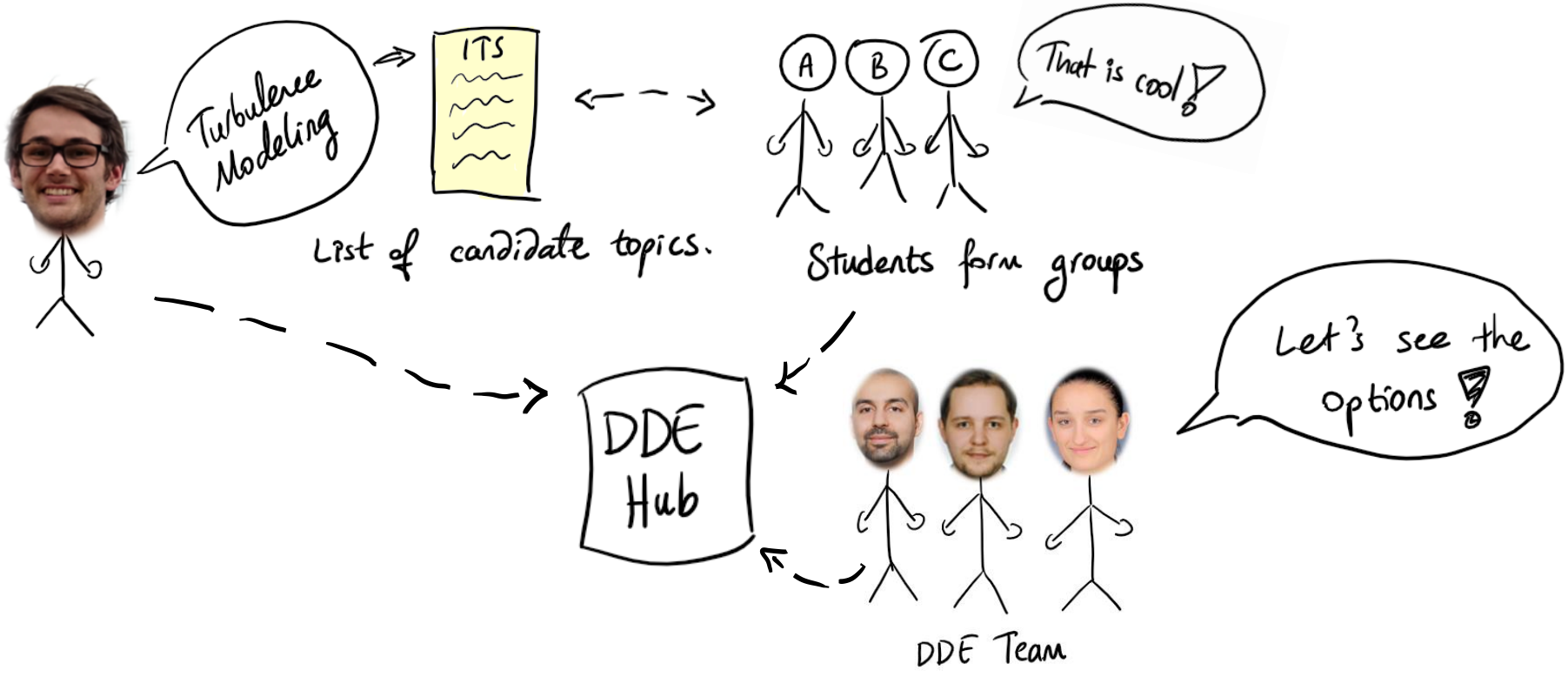
4. Dynamical Systems: State Space Models

5. Genetic Algorithms

6. Data driven control

Projects

* Working Frame:



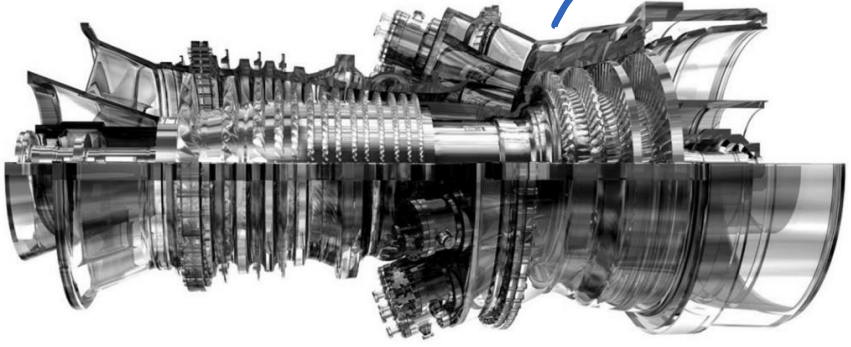
Active Sessions

- ❑ Colaboratory, or "Colab" for short, allows you to write and execute Python in your browser
- ✓ Zero configuration required
- ✓ Free access to GPUs (limited)
- ✓ Easy sharing and file management
- ○ You need a google account (dummy) // Local installation on PC

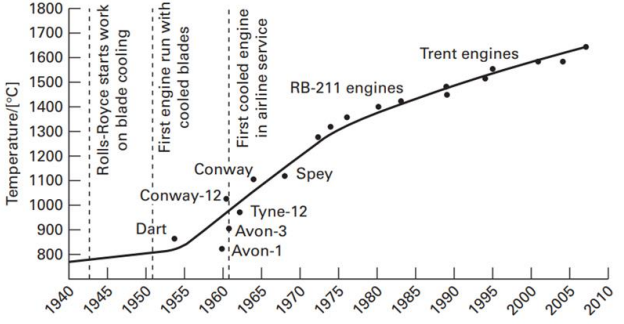


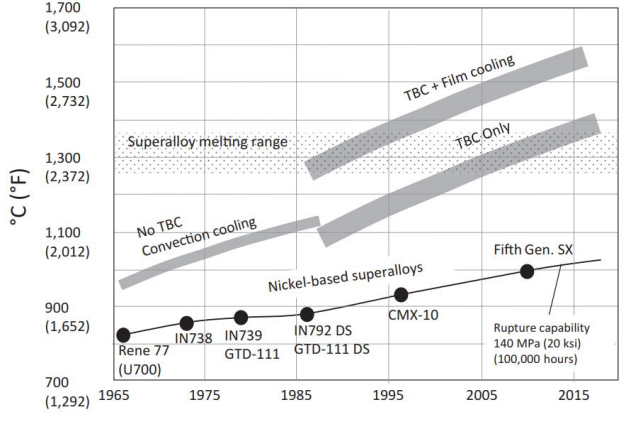
Project Descriptions

Turbine Blade Cooling



Gas Turbine

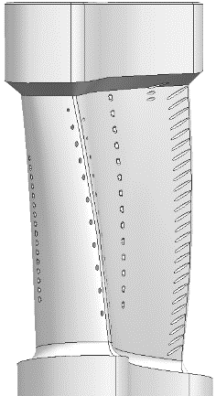


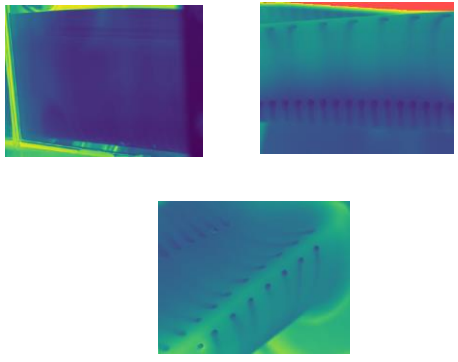


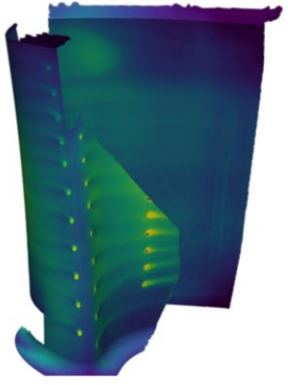
Topic #1: Film Cooling Performance Analysis I

Projection of IR Camera Measurements on a 3D Model

CAD Model + IR Images + — ML — ----> Image Process. Obj. Det. Feature Extr.

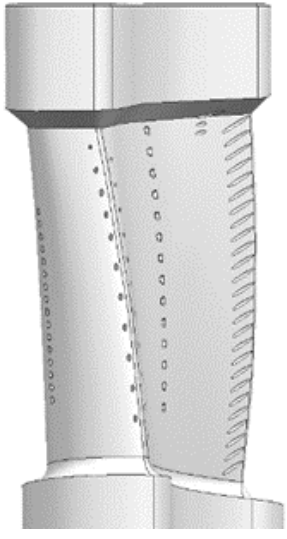


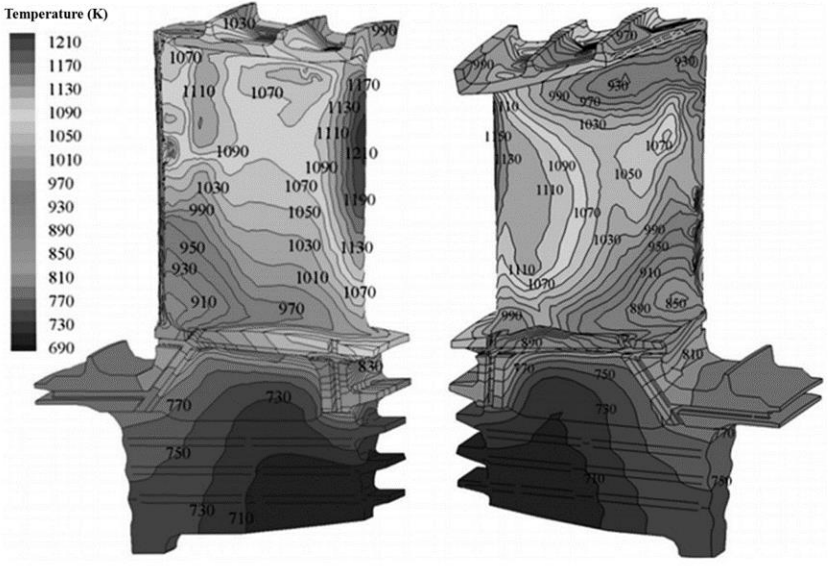


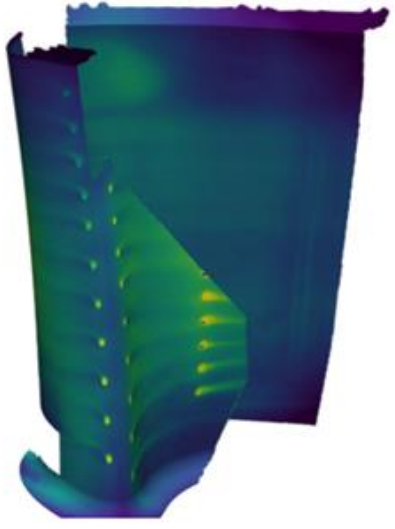


Topic #2: Film Cooling Performance Analysis II

Hot spot formations: Data Driven Risk Assessment







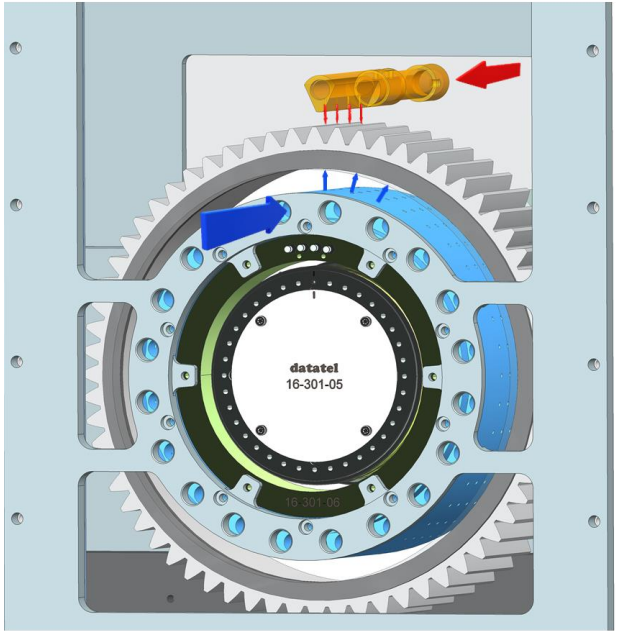
Topic #3 : Translating Sensory Data : Gearbox cooling in aero-engines

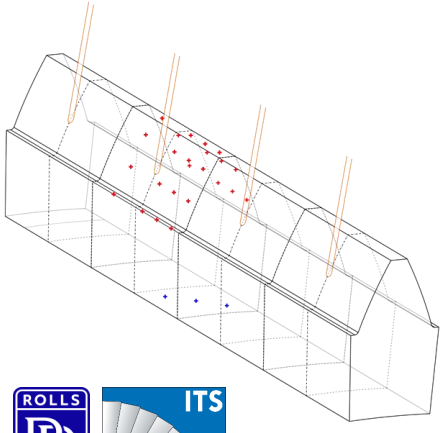
- Geared turbofan with optimized component speeds
- High power transmission over the planetary gearbox
- Need for an adequate cooling solution

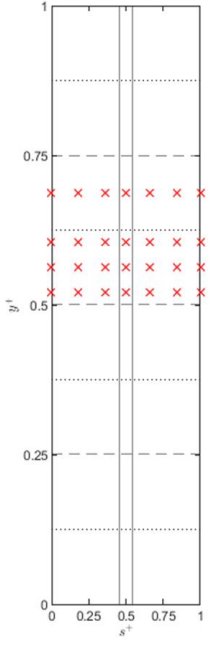
→ Experimental investigation to characterize cooling via oil jet impingement

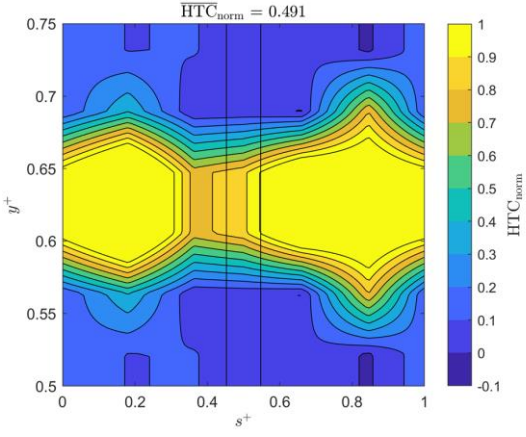
© Rolls-Royce

Topic #3 : Translating Sensory Data : Gearbox cooling in aero-engines

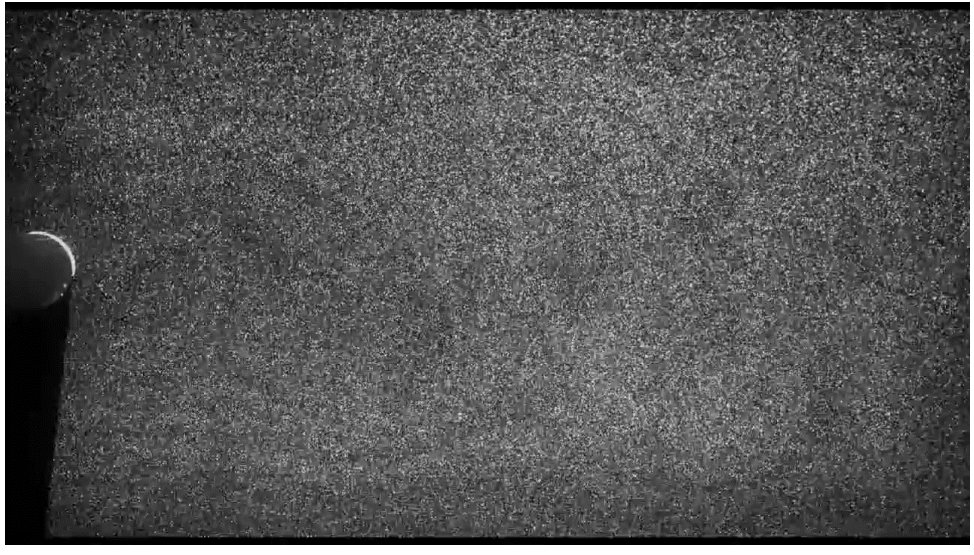








Topic #4: Particle Image Density Analysis in PIV Recordings

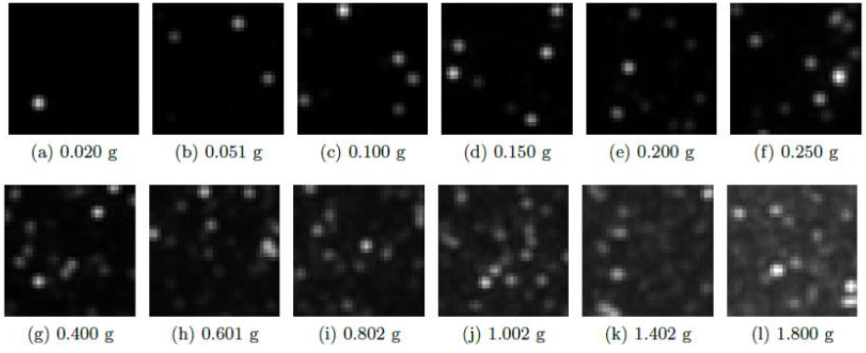


* flow is seeded with particles
* particles are illuminated
* Movement of particles
  ↳ velocity field

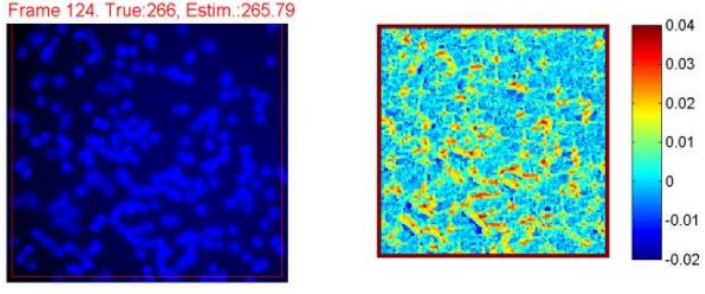
Topic # 4 : Particle Image Density Analysis in PIV Recordings

Karlsruhe Institute of Technology

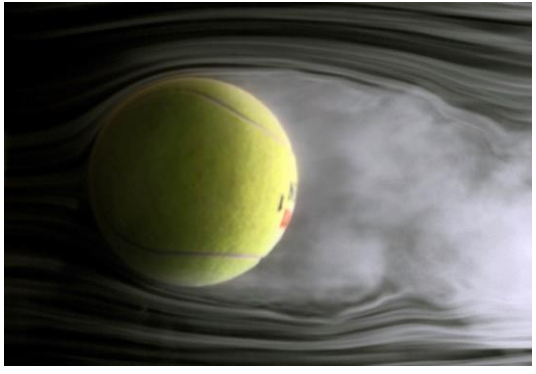
* Obj: Count objects in images
  - PIV particles



- ~ CNN based networks
- ~ operate with alternative particle densities
- ~ synth. & real datasets

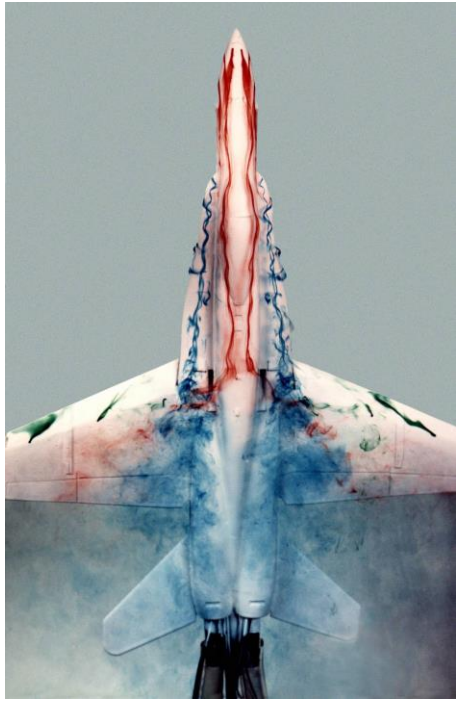


Decoding turbulence :

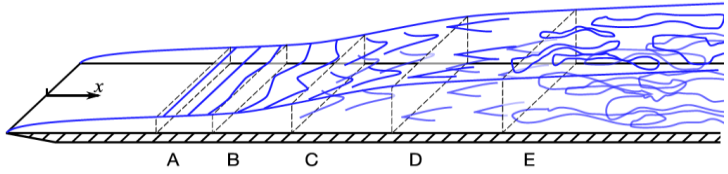


Quelle: NASA
(http://tennisclub.gsfc.nasa.gov/images/tennisball090500.jpeg)

Quelle: Wikipedia (https://en.wikipedia.org/wiki/Turbulence)



Quelle: NASA
(http://www.nasa.gov/centers/armstrong/multimedia/imagegallery/FVF)



"Big whirls have little whirls that feed on their velocity, and little whirls have lesser whirls and so on to viscosity"

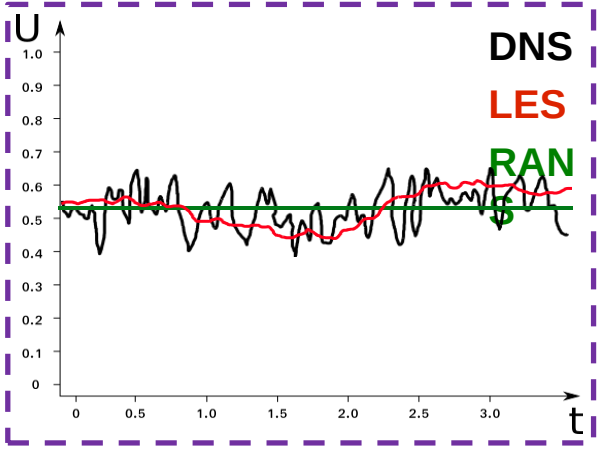
L.F. Richardson 1922

"We really don't know a whole lot for sure about turbulence. And worse, we even disagree about what we think we know! ... Thus it might be wise to view most 'established' laws and theories of turbulence as more like religious creeds than matters of fact."

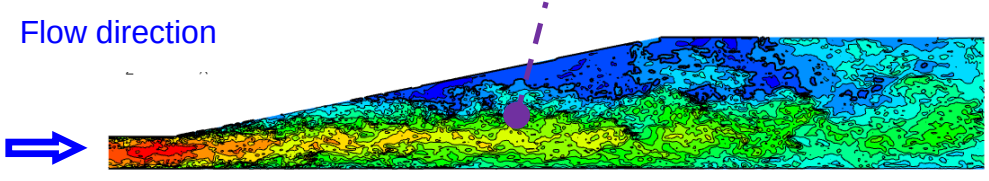
W. K. George 2013

Decoding turbulence:

* Modeling turbulence

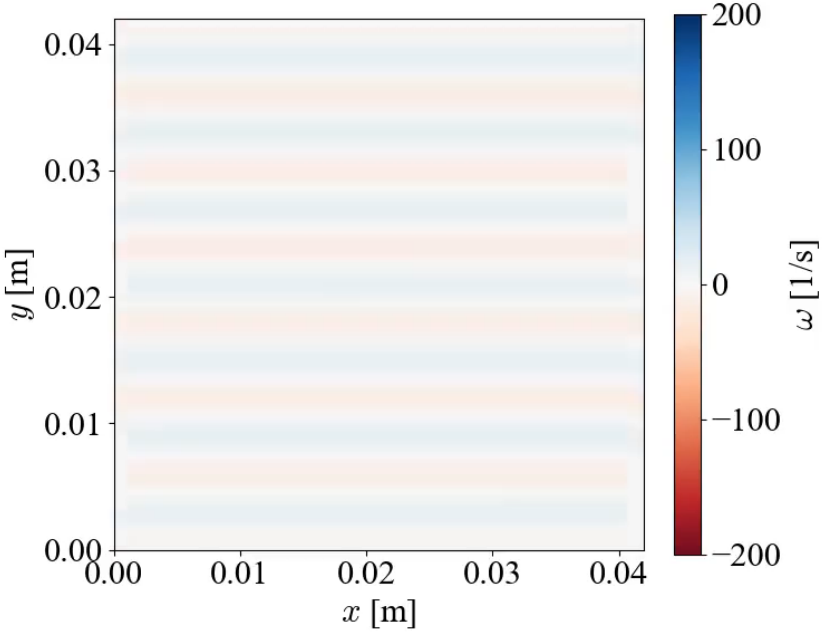


Flow direction



- **Large-Eddy-Simulation (LES)**
  - Spatially filtered N-S equations
  - Inherently 3D & transient
  - Larger vortex structures are simulated directly without any models
  - Smaller vortex structures are statistically modelled
- **Direct-Numerical-Simulation (DNS)**
  - No Modelling
  - Inherently 3D & transient

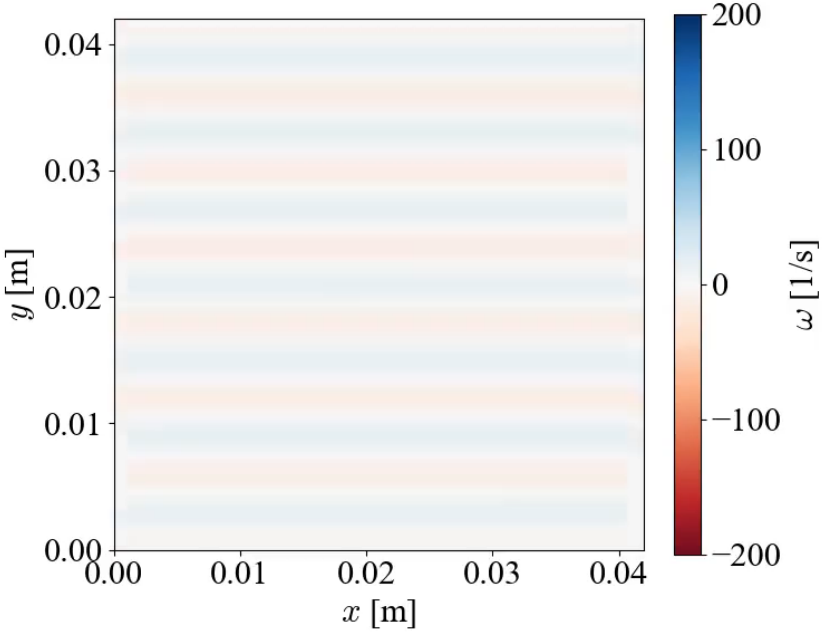
Topic #5 : Decoding turbulence I : Feature Analysis



* Modeling turbulence → DNS, LES, RANs

Latent Space Representation of sub-grid models

Topic #6 : Decoding turbulence II : Graph. NN

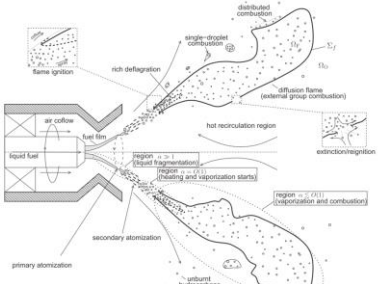


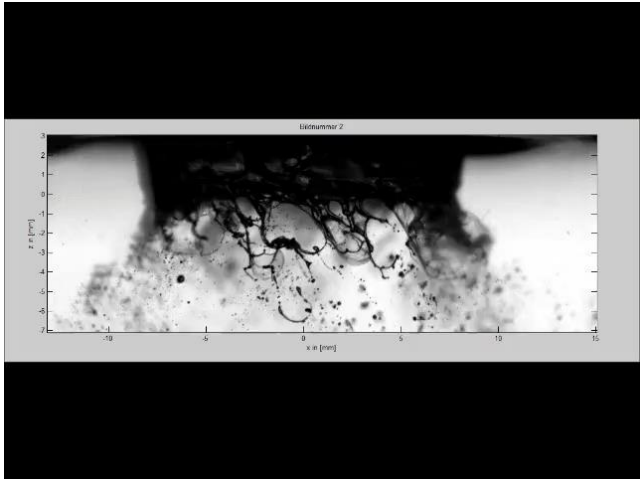
* Modeling turbulence → DNS, LES, RANs

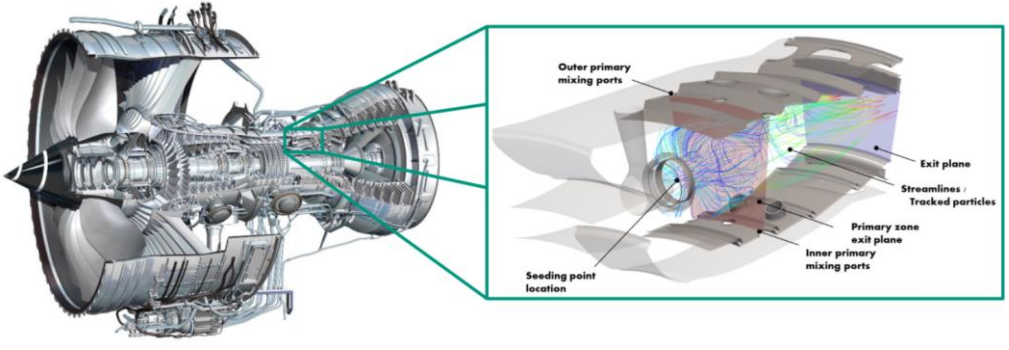
* Modeling turbulence

⇒ Simulation over NN architectures

Topic #7 : NN based spray model for airblast atomization



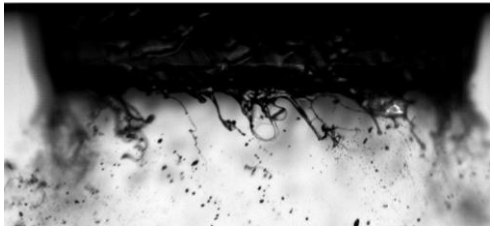


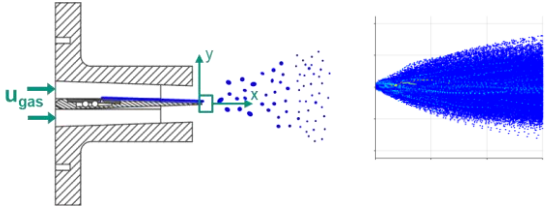


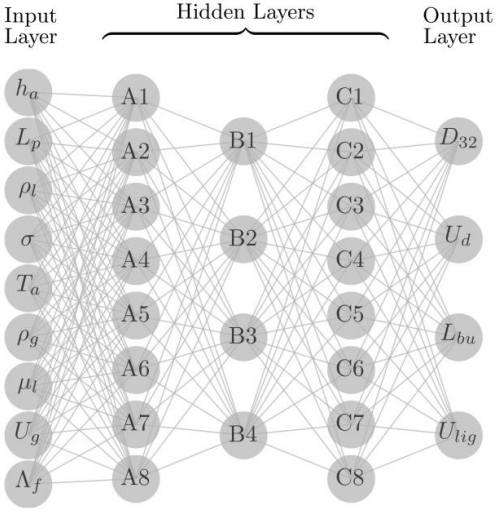
Primary Breakup

Topic #7 : NN based spray model for airblast atomization

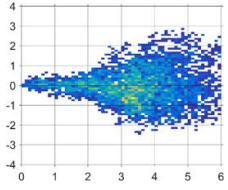
Exp. & Num. Data







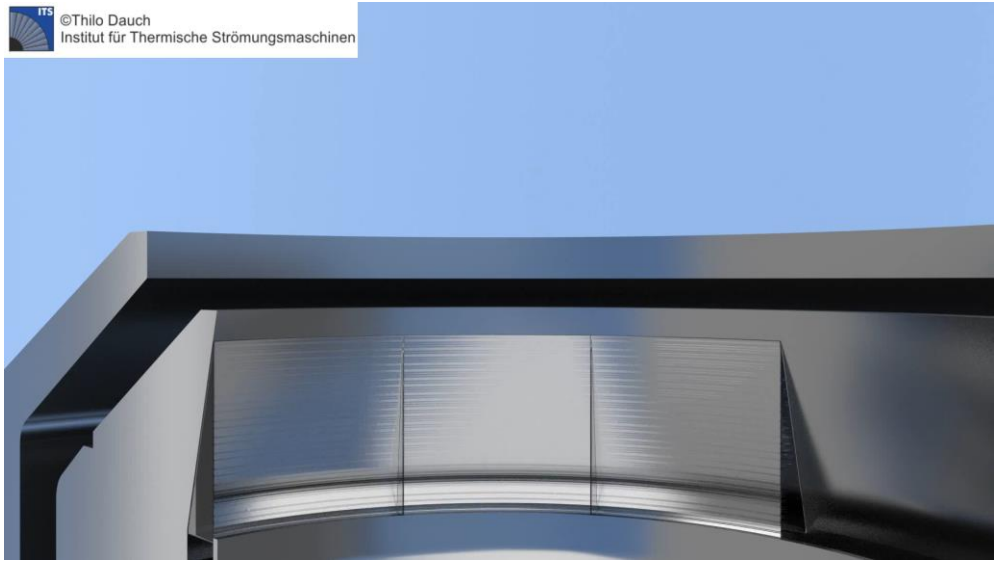
Global Statistics ✓

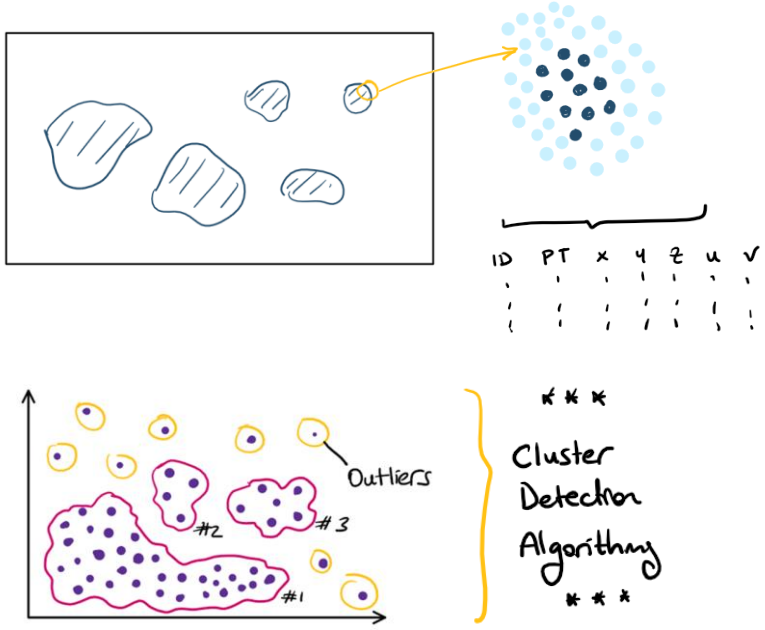


?

"Digital twin"

Topic #8: Clustering in Two Phase Flow Simulations: Data-Driven Spray Analysis





Topic # 9 : NN for Data Management

- 3D ~ DNS simulations
- Multiphysics modeling
- Stochastic models
- Fully Lagrangian models

...

} "Big Data"

- [cm × cm] 2D 2 Phase Transient } ~ 10 TB

Data Storage

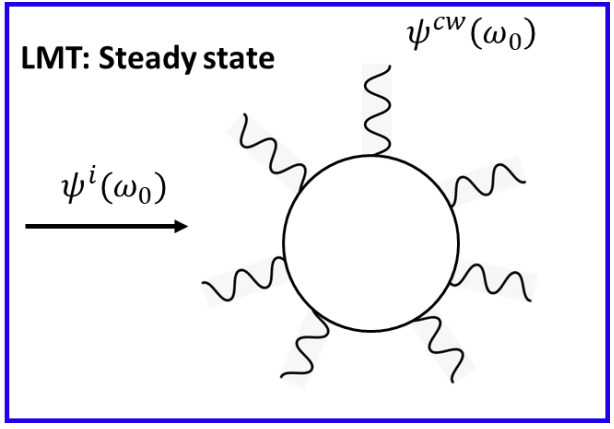
- Capital cost
- Op. cost
- maintenance
...
- CO_2 emissions

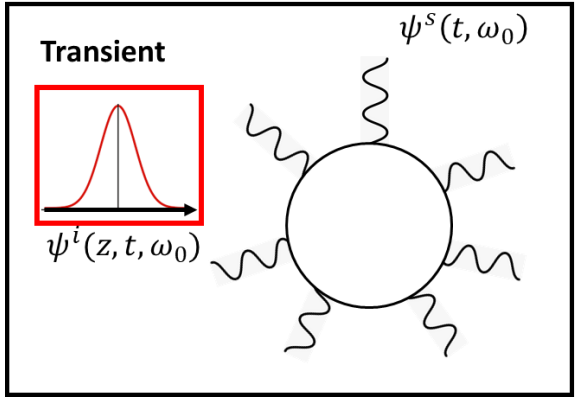
- What if we store them as latent representations ?

Topic # 10 : Femto pulse Lasers :

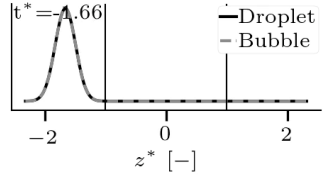
Light Scattering in a cloud of particles

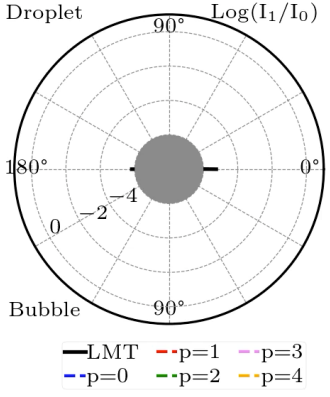
* Typical femtopulse ~ 100 fs } $\Delta t = 1\,s$; $ft \Rightarrow s$, ⇨ 3 million years !

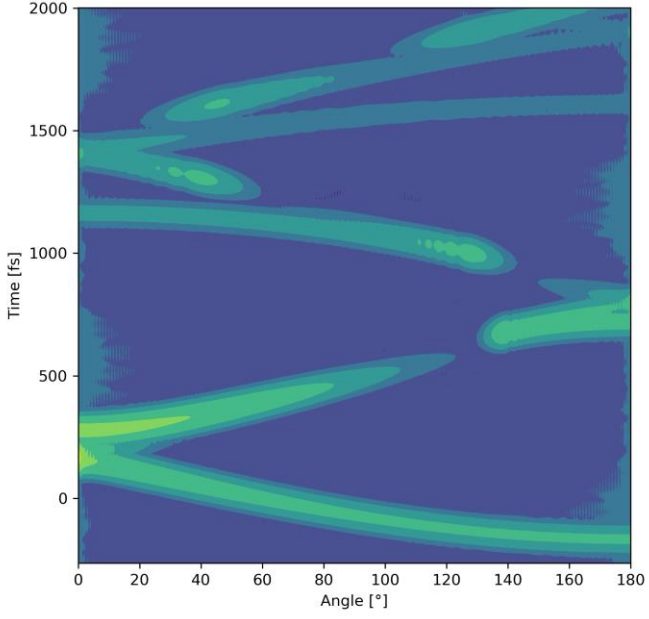


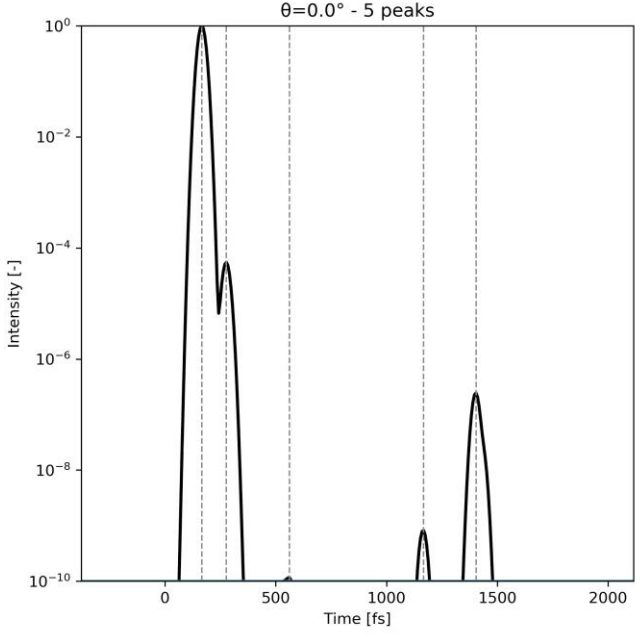


Topic #10 : Femto pulse Lasers : Light Scattering in a cloud of particles

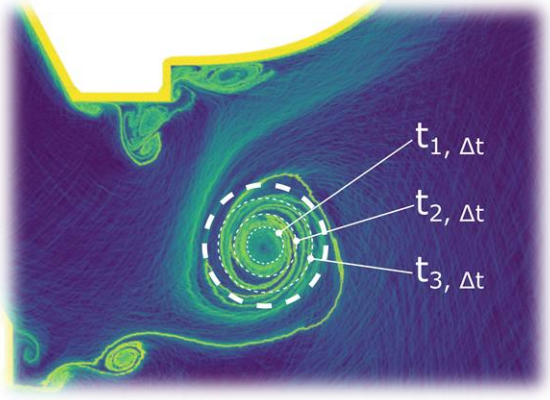




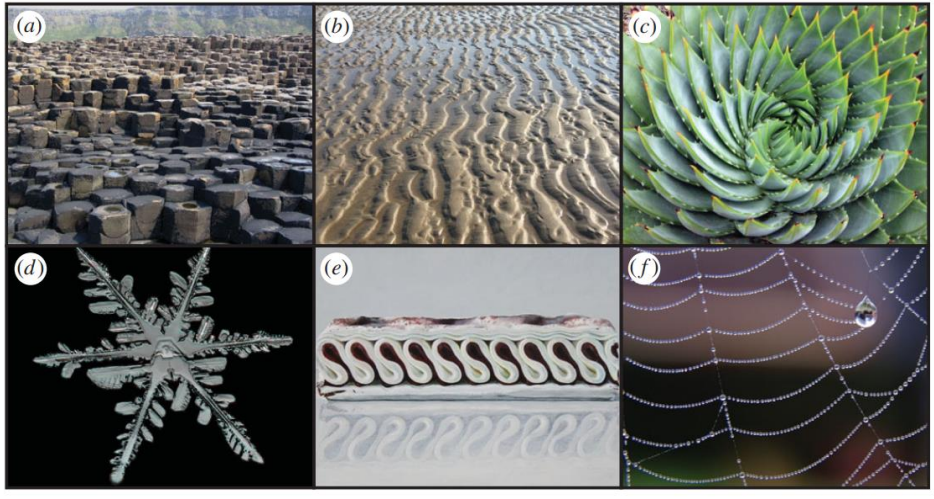


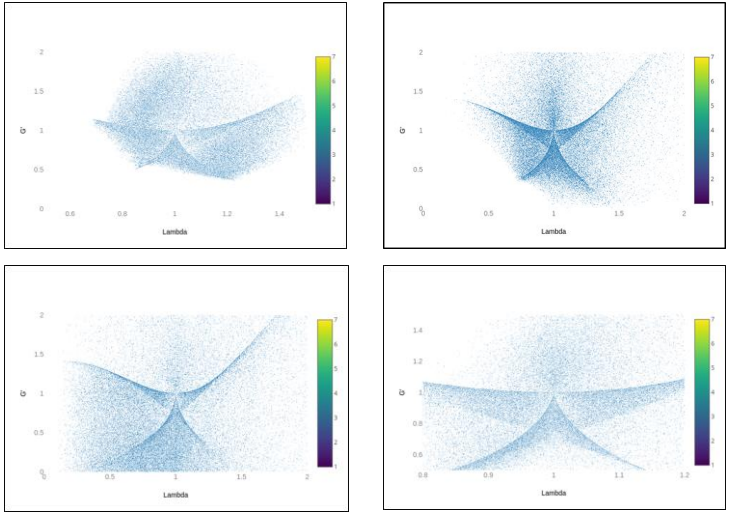


Topic # 11 : What is common betw. the Roman Empire, Symphony # 9 & mixing fluid layers



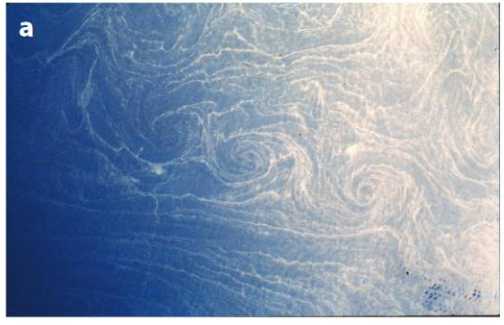
Topic # 11 : What is common betw. the Roman Empire, Symphony # 9 & mixing fluid layers

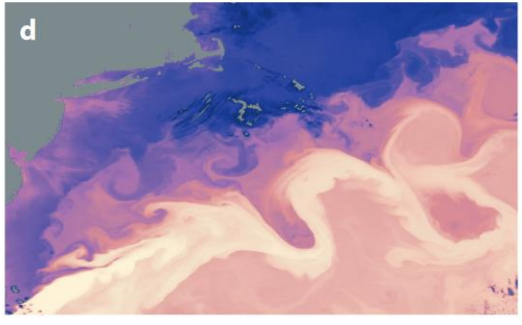


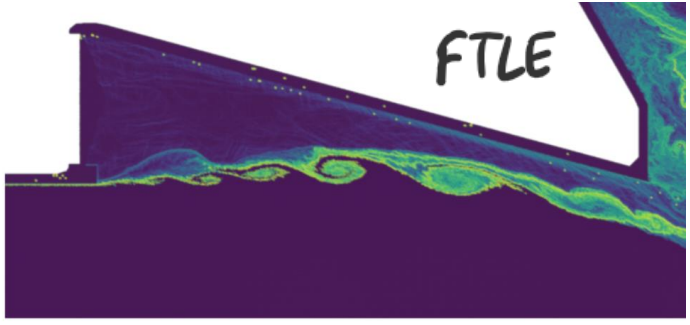


" Lethargy Concept "

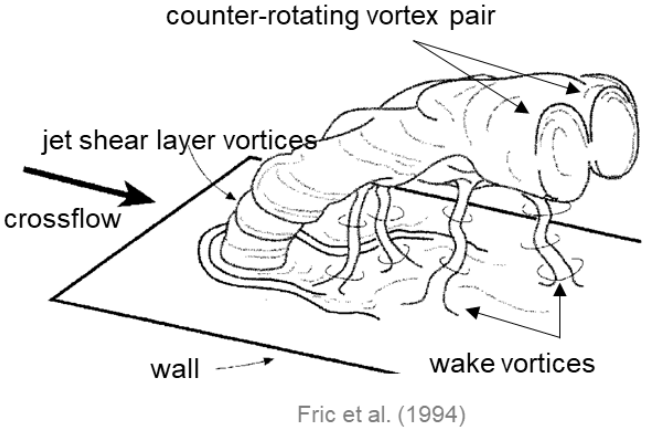
Topic #12 Pysrcal interpretation of LCSs







Topic #13: Time resolved flow field analysis in film cooling

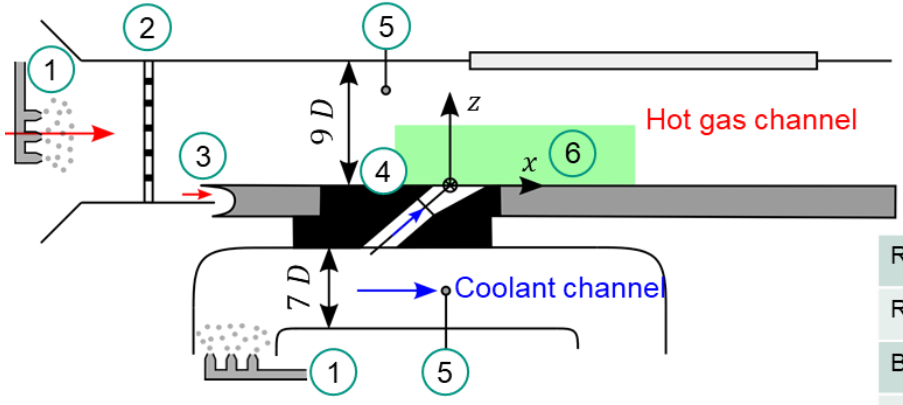


Fric et al. (1994)

- improve understanding of film cooling & coolant – hot gas interaction at realistic engine conditions
  - → Stereo Particle Image Velocimetry
- data-driven analysis of time-resolved flow field data
  - → detect coherent flow structures
  - → identify relevant attributes
    - → frequency, energy content, …

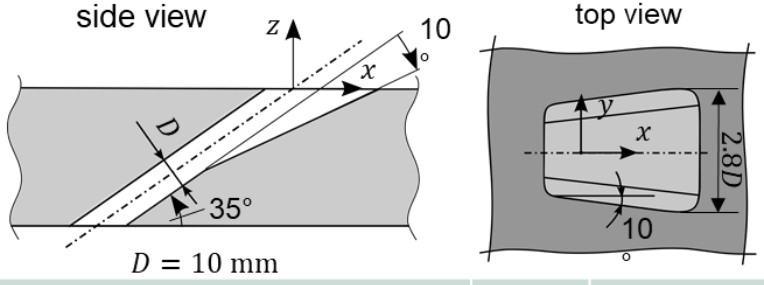
Topic #13: Time resolved flow field analysis in film cooling

- engine realistic investigation of film cooling



1 Seeding particles
2 Turbulence grids
3 Boundary layer suction
4 Blowing module
5 Pitot probe
6 FOVs / light sheet plane

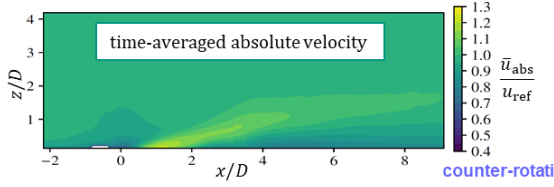
10°-10°-10° laidback fan-shaped hole

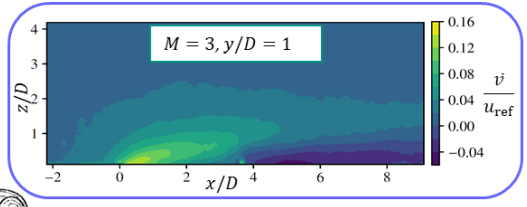


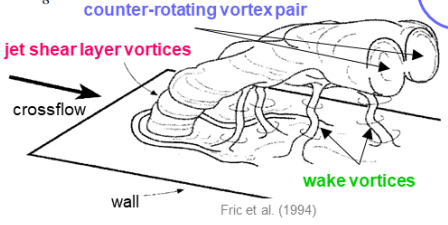
$D = 10$ mm

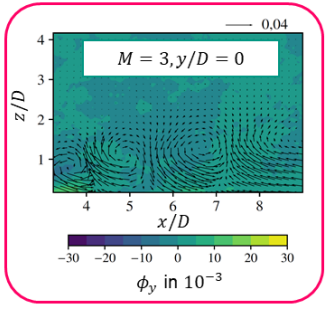
Reynolds number hot gas channel	$Re_{D,\mathrm{h}}$	$13 \times k$
Reynolds number coolant channel (∥ or ⊥)	$Re_{D,\mathrm{cc}}$	$5k - 3k$
Blowing ratio	M	0.5 ... 3.0
Total hot gas temperature	$T_{\mathrm{t,h}}$	510 K
Total coolant temperature	$T_{\mathrm{t,k}}$	300 K
Turbulence intensity hot gas	Tu_{h}	8.2 %

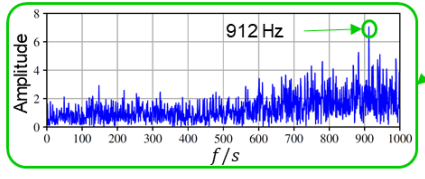
Topic #13: Time resolved flow field analysis in film cooling

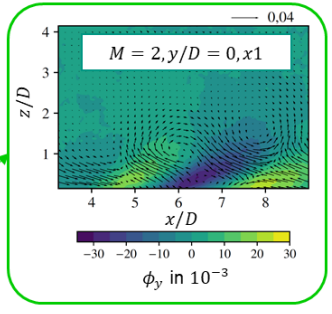


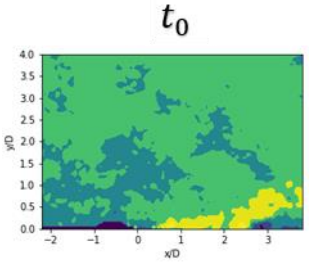










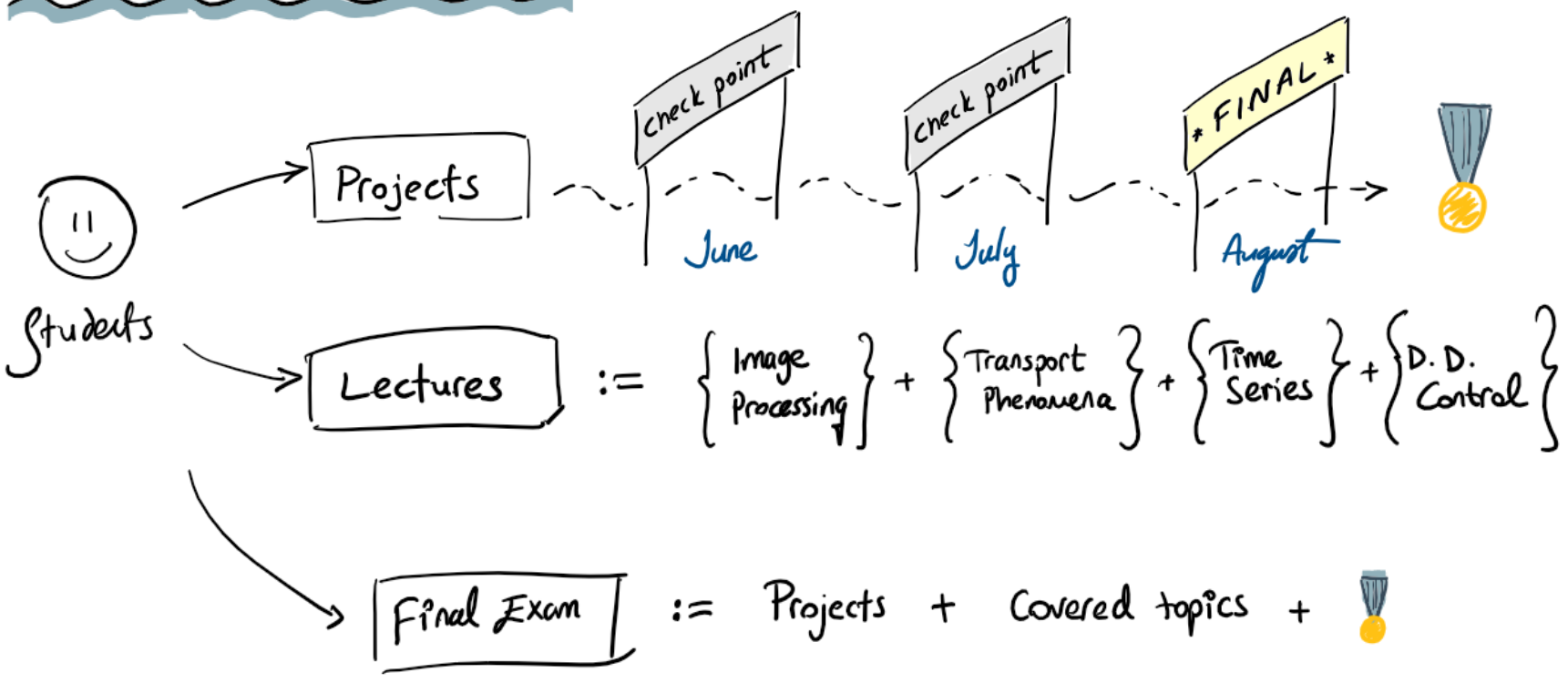


Topic # n ....

any other ideas?

more than welcomed!

What is this lecture about ?



Machines will be capable, within twenty years, of doing any work a man can do.

Herbert Simon, 1965

***

From three to eight years, we will have a machine with the general intelligence of an average human being.

Marvin Minsky, 1970

***

“The most fruitful areas for the growth of the sciences were those which had been neglected as a no-man’s land between the various established fields.”

Norbert Wiener, 1948