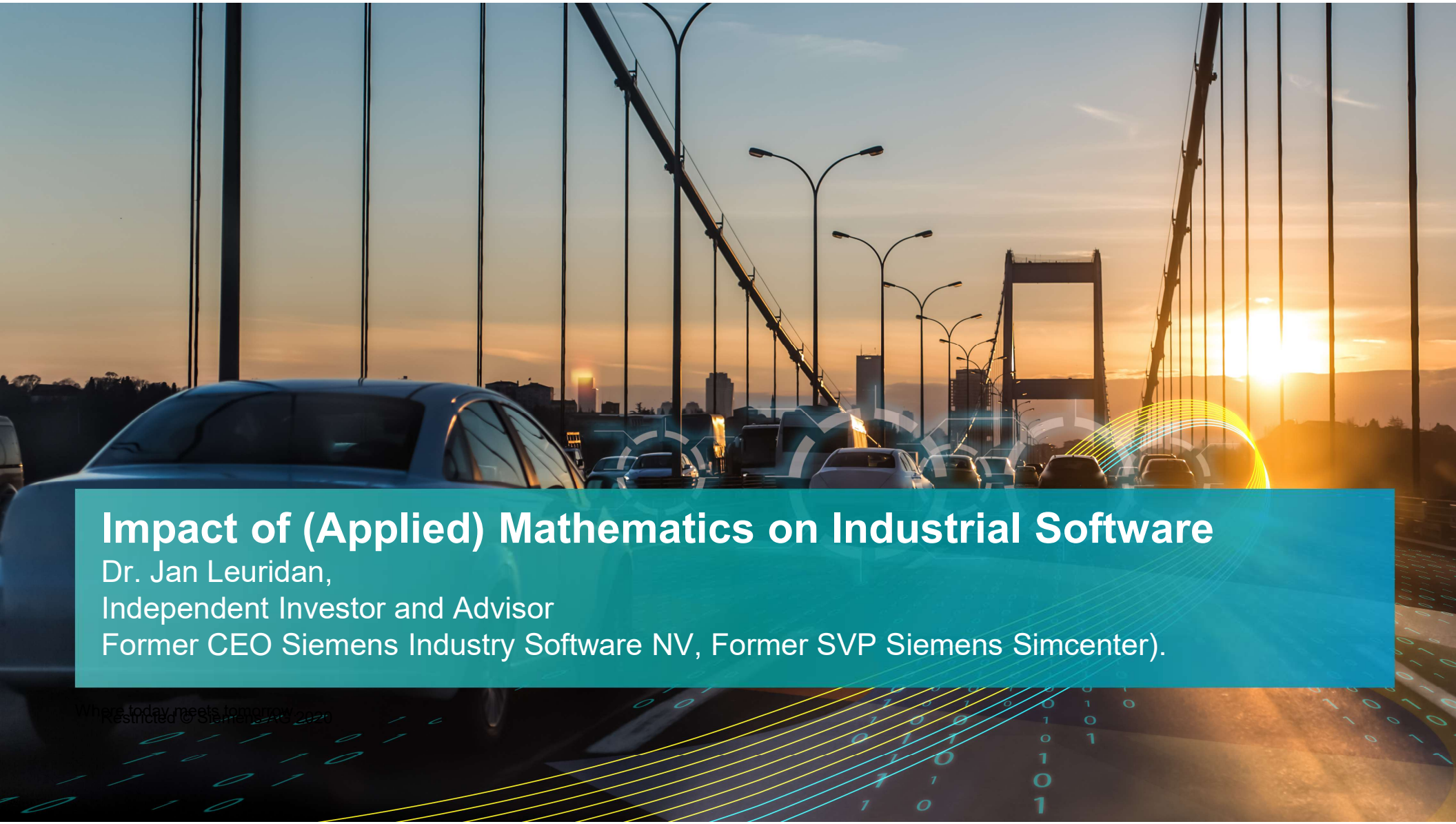


Impact of (Applied) Mathematics on Industrial Software

Dr. Jan Leuridan,
Independent Investor and Advisor
Former CEO Siemens Industry Software NV, Former SVP Siemens Simcenter).

“Industrial Software” Market - Companies

“Industrial Software”

- Software applications for design (CAD), engineering (CAE/SImulation, CAT/Testing), manufacturing (CAM), manufacturing operations (MES, MOM), and maintenance (APM) of products.
- Also PLM (Product Life Cycle Management) incl. MDA (Mechanical Design Automation) and EDA (Electric/Electronic Design Automation)
- Also referred to as software applications enabling “Digital Twin” of a product
- Started in 1960’s. Now a very sizable business, with market size: +45 b$ and CAGR: +9%

Companies

AUTODESK
Rev.: +6.1 b$
Mkt Cap: +63 b$

SIEMENS
Industrial Software Unit
Rev. (Est.): +7.5 b$
Part of Siemens

SYNOPSYS®
Rev.: +8.5 b$
Mkt Cap: +77 b$
(Partly incl. Ansys)

ptc
Rev.: +2.3 b$
Mkt Cap: +21 b$

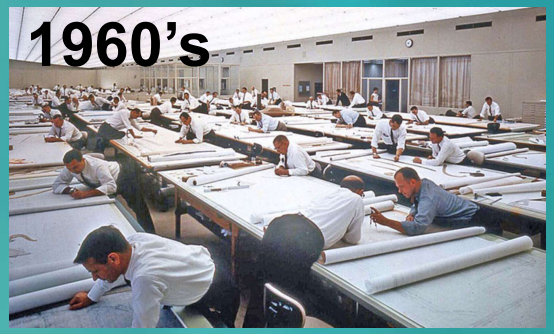
DASSAULT SYSTEMES
Rev.: +6.7 b$
Mkt Cap: +32 b$

cadence
Rev.: +5.2 b$
Mkt Cap: +87 b$

Very “valuable” companies - Market capitalization at high multiples (upto +10 !) of revenue (!)

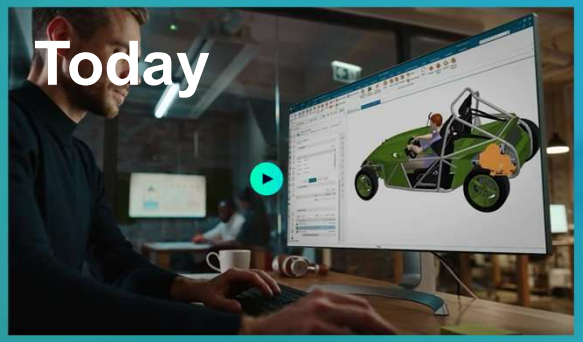

Siemens Digital Industries Software

Computer Aided Design (CAD)

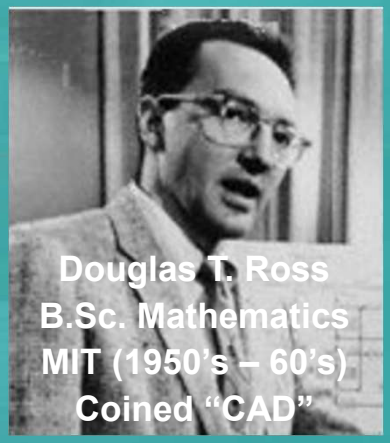


From "Drawing Board"
To "CAD"
and Digital Mock-Up (DMU)

Disruptive Innovation



Driven by applied mathematicians and engineers … working at Universities and Industry

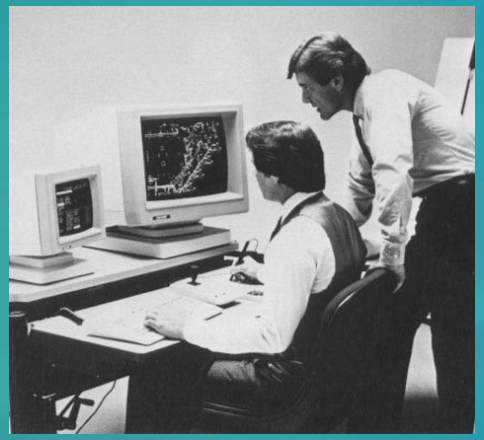


Douglas T. Ross
B.Sc. Mathematics
MIT (1950's – 60's)
Coined "CAD"

From early 1960's:

The aircraft industry started to develop CAD programs:
Proprietary software developed at Boeing;
CADAM by Lockheed; McAuto by McDonnell Douglas (later Unigraphics); CATIA by Dassault Aviation.

Similar initiatives in automotive industry, driven by General Motors (US) and Renault and Citroen (France)

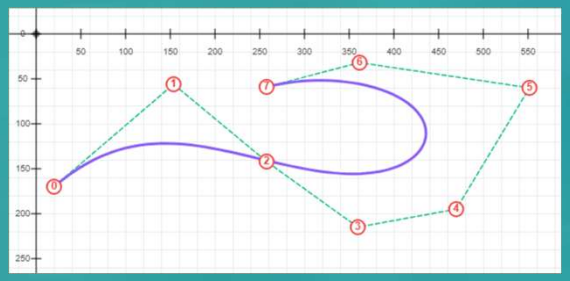


Computer Aided Design (CAD)
Enabled by Bernstein Polynomials – Bezier Curves

Pierre Bezier
(1910-1999)
Engineer at Renault
UNISURF (CAD Software)

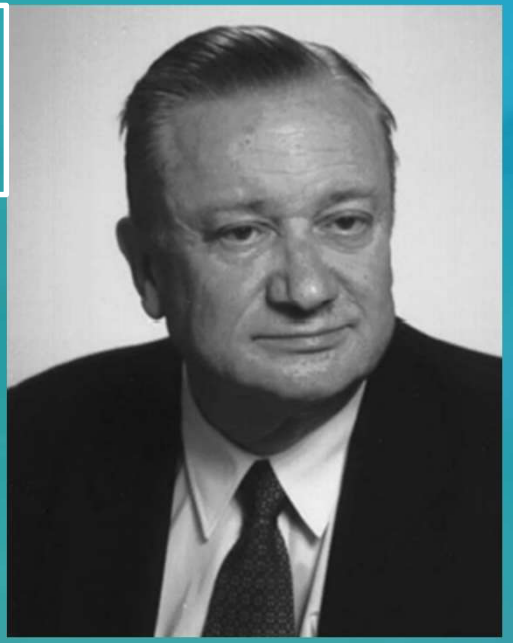
Recursive method to evaluate Bernstein Polynomials
(Sergueï Bernstein – 1880-1968)

Bezier Curves



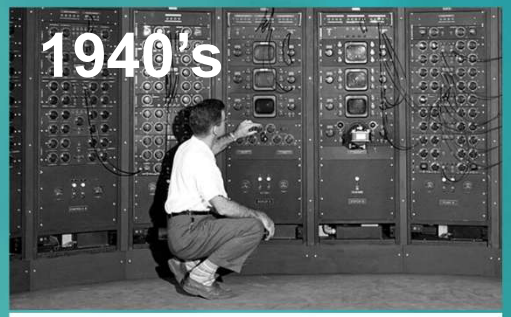
Bezier curves are a type of parametric curve widely used in computer graphics to model smooth and scalable shapes. They are defined by a set of control points that influence the shape of the curve.

From 2D to 3D



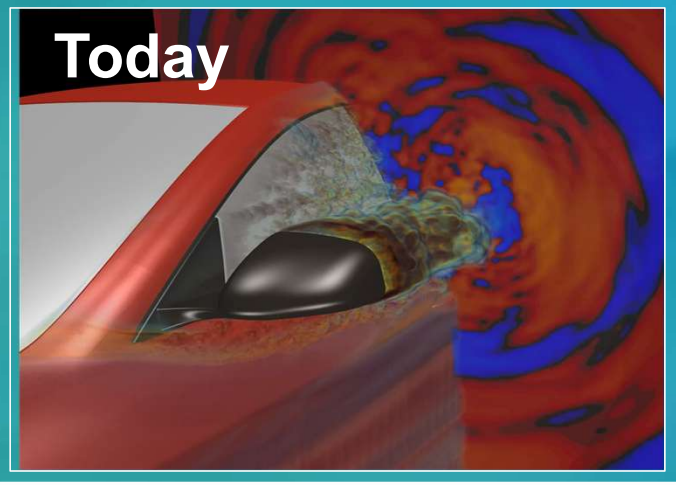
Paul de Casteljau
(1930-2022)
Mathematicien at Citroen
SADUSCA (CAD Software)

Computer Aided Engineering (CAE/Simulation)

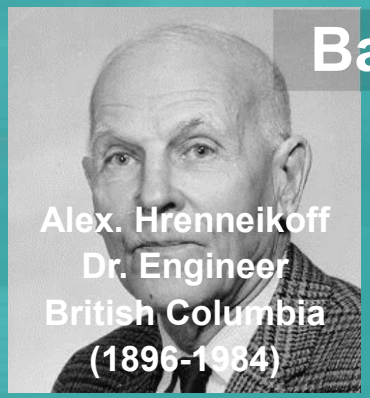


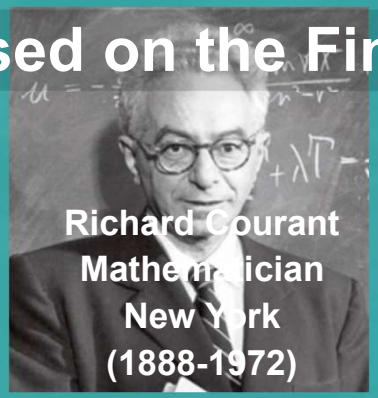
From "Calculus"
To "CAE/Simulation"
for Solving
Differential Equations
(Physical properties of products)

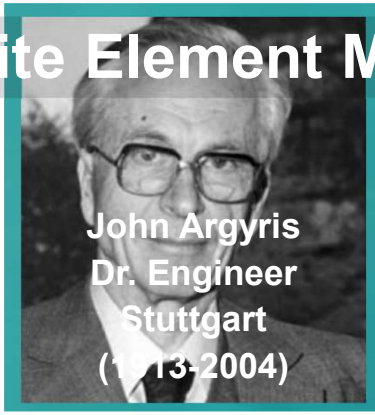
Disruptive Innovation

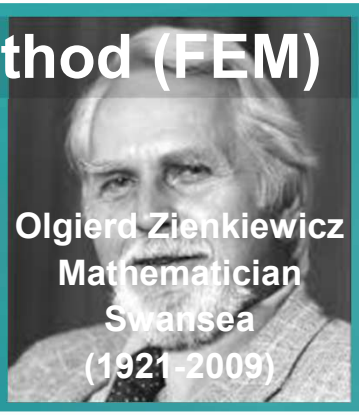


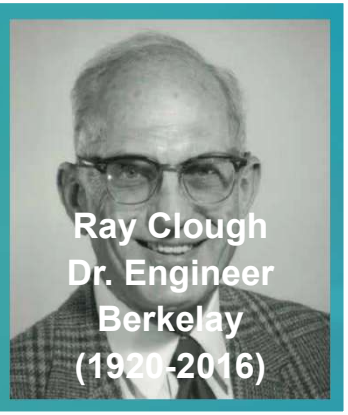
Based on the Finite Element Method (FEM)


Alex. Hrenneikoff
Dr. Engineer
British Columbia
(1896-1984)


Richard Courant
Mathematician
New York
(1888-1972)


John Argyris
Dr. Engineer
Stuttgart
(1913-2004)


Olgierd Zienkiewicz
Mathematician
Swansea
(1921-2009)


Ray Clough
Dr. Engineer
Berkelay
(1920-2016)

Initial focus (1950's): Structural Analysis

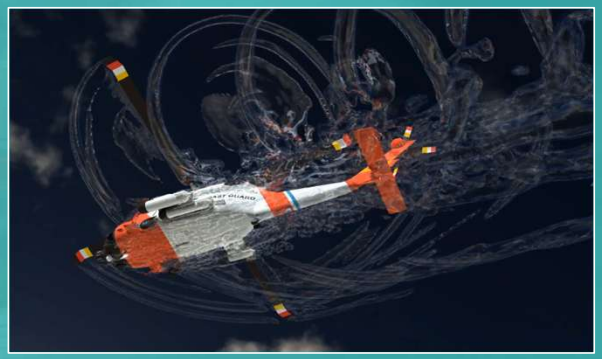
Computer Aided Engineering (CAE/Simulation)
Covering all Physics – Enabling "Digital Twin"

Initially driven by large Aerospace Programs:

- NASA Apollo Program - Initiated the NASTRAN FEM Software (initially Open Source)
  Triggered start of MSC – McNeal-Schwendler in 1963 (First CAE/Simulation company)
- Developments for ESA – Initiated ASKA FEM Software (Univ. of Stuttgart)

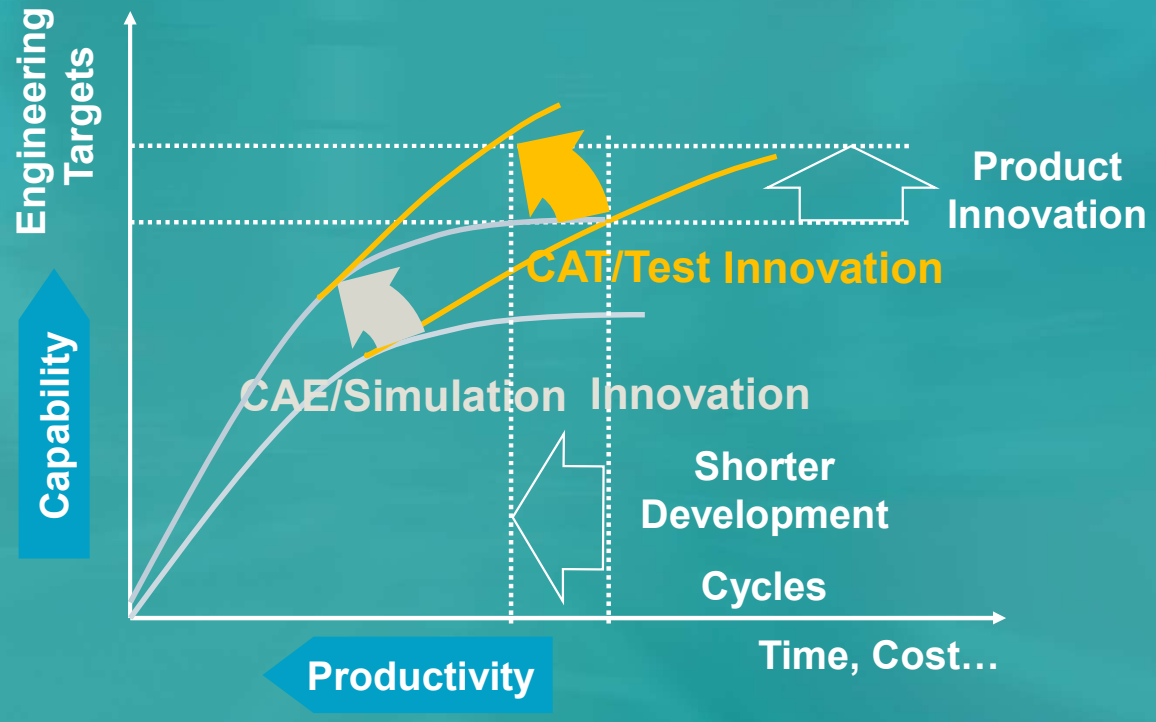
The method has since been generalized for the numerical modeling of all physics

- Globally in use throughout Aerospace, Automotive e.a. Industries
- Exponential Increase of Capabilities of Simulation ... Enabling "Digital Twin"



Towards "Zero (physical) Prototyping" – But, are we there yet?

CAE/Simulation and CAT/Test
Interacting together – Driven by relentless push for Product Innovation



Example of Test Innovation

Ground vibration test drastically reduced:
(Siemens/LMS Simcenter Test.Lab)

- A380 2005 ➔ 1 Month
- A400M 2007 ➔ 3 Weeks
- A350-900 2013 ➔ 9 Days
- A350-1000 2017 ➔ 2 Days

"Shaking things up – Airbus speeds up ground vibration testing for the A350-1000"

Airbus Newsroom, 13/02/2017

Source Youtube https://www.youtube.com/watch?v=L8WMohu83zo

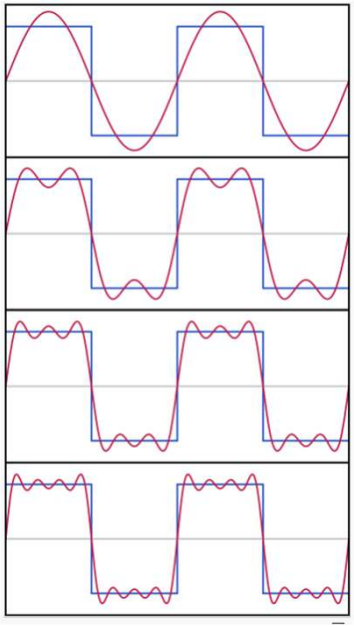
Computer Aided Testing (CAT/Test)

Joseph Fourier
(1768-1830)
Mathematician/Physicist
Studied under Lagrange and Laplace

Any periodic function
can be decomposed
in a series of trigonometric functions

$$f(x) = \sum_{n=-\infty}^{+\infty} c_n(f) \mathrm{e}^{\mathrm{i}2\pi \frac{n}{T} x}$$

$$c_n(f) = \frac{1}{T} \int_T f(t) \mathrm{e}^{-\mathrm{i}2\pi \frac{n}{T} t} \, \mathrm{d}t.$$



Basis for Harmonic/Spectral Analysis
Essential in the analysis of most physical phenomena
(Based on Fourier Analysis / Fourier Synthesis)

Computer Aided Testing (CAT/Test)
Fast Fourier Transform (FFT) – Making Fourier Analysis Practical

James Cooley
Ph.D. Mathematics
IBM
(1926-2016)

John Tuckey
Ph.D. Mathematics
Bell Labs,
U. Princeton
(1915-2000)

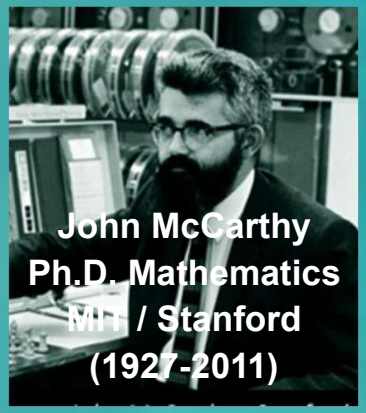
1965 – Cooley-Tuckey Fast Fourier Transformation (FFT)
Breakthrough acceleration for Fourier Analysis

E.g. Time sample of 4096 data points:
DFT would require 30 Million operations.
FFT would do with 30.000 operations. 1000 Faster

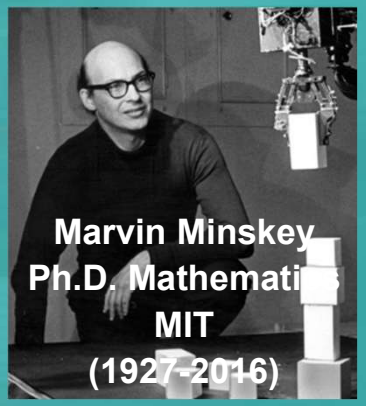
Computing revolution in 1970's, including emergence of mini-computers, made FFT one of the indispensable algorithms in digital signal processing.

At the heart of any digital spectral analyzer …
the speed of FFT defined "Real Time" competitiveness

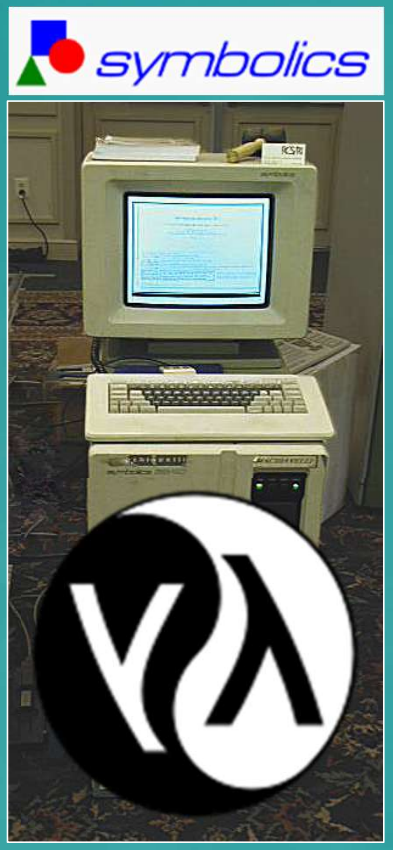
Impact of AI on Industrial Software
Early adoption, starting 1980's …



John McCarthy
Ph.D. Mathematics
MIT / Stanford
(1927-2011)



Marvin Minskey
Ph.D. Mathematics
MIT
(1927-2016)



1980's – Based on Research at MIT AI Labs:

- "Expert" Systems
- LISP Programming Language
- Symbolics – "LISP Machine" (1980-1996)

ICAD - "Intelligent" CAD (Concentra, UK)

- Founded 1984
- "Knowledge Based Engineering – KBE"
- CAD Software embedding KBE, programmed on LISP
- Developed for Symbolics, later ported to UNIX (after LISP became available as Open Source)
- Enables users to encode design knowledge using a semantic representation that can be evaluated for Parasolid (a CAD kernel) output
- Acquired by Dassault Systemes 2001

Interest evaporated during AI winter (1990's-2000's)

Impact of AI on Industrial Software Renaissance …

- ML running in background to support users in setting up ever more complex CAE/Simulation models
- Integrate ML into solvers, e.g. to improve/accelerate convergence
- ML running in background to support users in getting insights in simulation results (not unlike use in medical imaging applications)

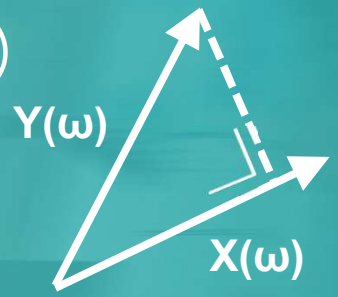
Concluding Thought
(Applied) Mathematics … mattered, matters, and will continue to matter

2025

How many methods for estimating a Frequency Response Function (FRF - H(ω)) from measurements of input X(ω) and output Y(ω) on a under test?

So solving: $Y(\omega) = H(\omega) * X(\omega)$

1

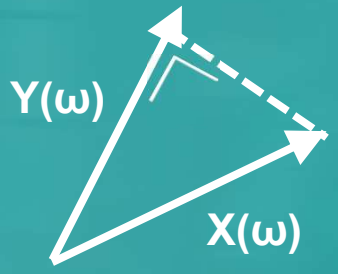


$Y(\omega)+\varepsilon = H_1(\omega)*X(\omega)$

H_1 "Error on the Output"

Quite common …

2

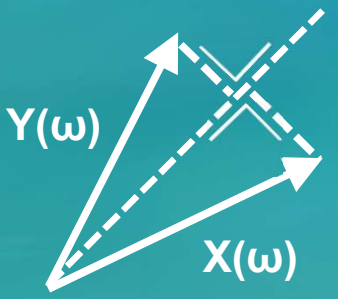


$1/H_2(\omega)*Y(\omega) = X(\omega)+\varepsilon$

H_2 "Error on the Input"

Julius Bendat & Alan Piersol (1974)

3



$B(\omega)*(Y(\omega)+\varepsilon) = A(\omega)*(X(\omega)+\delta)$

$H_V = A/B$ "Error on Output and Input"

Manfred Schroeder (1977)

Generalized by Håvard Vold (1985) … H_V

Hypothetical, what would ChatGPT have suggested on this topic, in 1973, 1976, 1984?


Thank You!