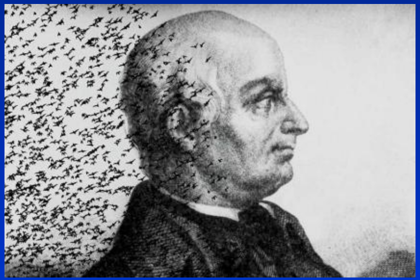
A History of Cardiac Ultrasound

Prof. George Sutherland

History of Cardiac Ultrasound

- Lazzaro Spallanzani – born Scandiano, Modena, Italy 1729-99.
- Jesuit priest. Universities of Bologna, Modena, Padua, Pavia.

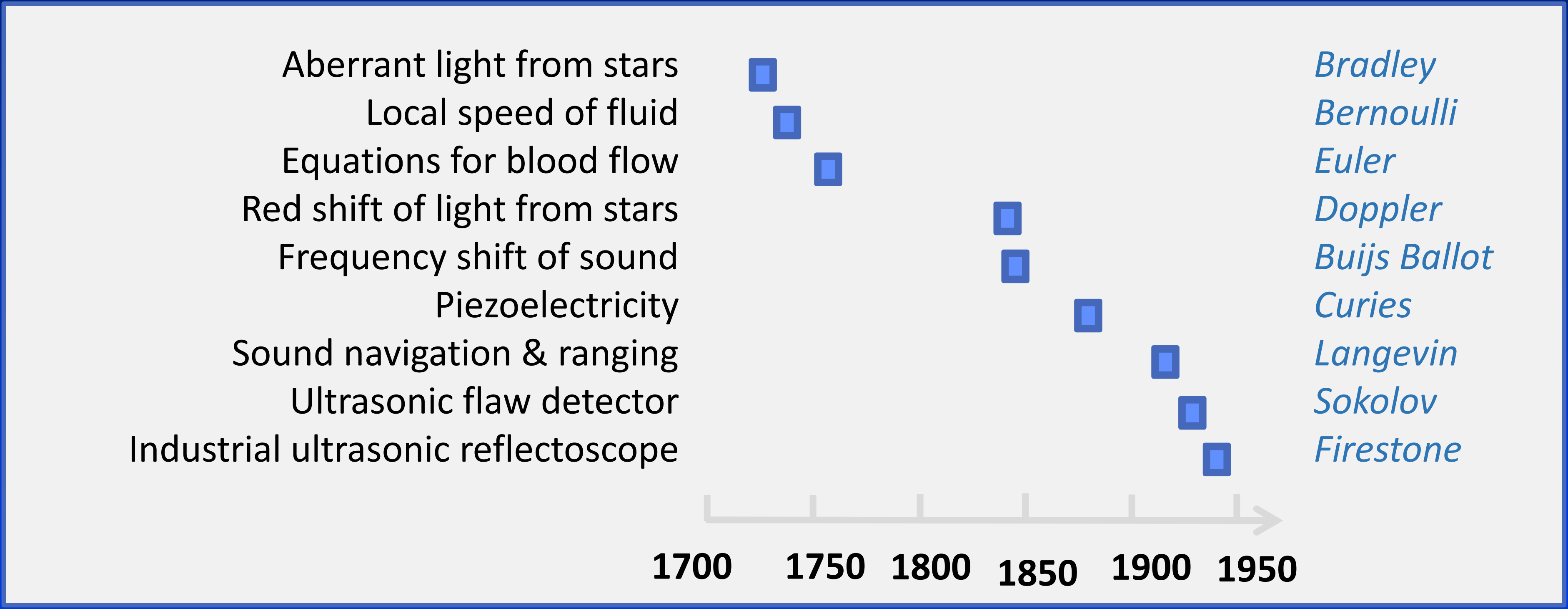


- Experimental studies in bodily function, reproduction and animal echo-location.
- 1793 - Showed that reflected echoes of an inaudible ultrasound signal enabled bats to navigate.
- These findings are the basis of all subsequent developments in clinical cardiac ultrasound!

History of Cardiac Ultrasound

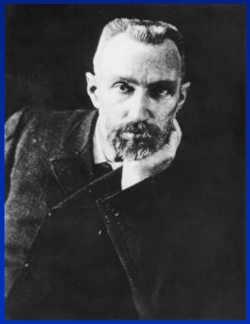
The Development of the Basic Principles

1700 - 1950



History of Cardiac Ultrasound

Transducer Development



- 1880 – Paris

- The Curies (Curie P. & J.) discovered piezoelectricity and used crystals to create ultrasonic waves.

- Comptes Rendu 1880 ;91:291-5.

History of Cardiac Ultrasound

The Military Development of Ultrasound

!890 - 1940

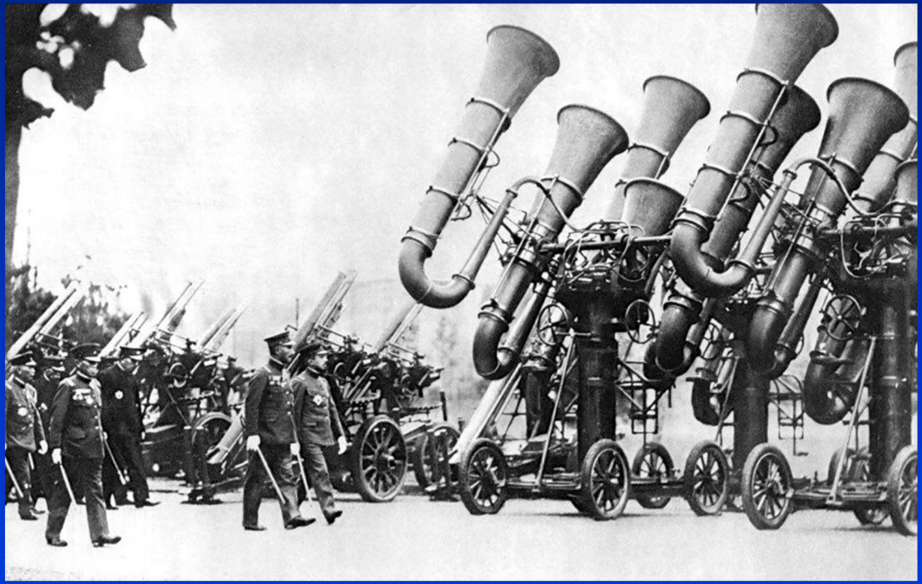
1912 - Lewis Richardson.

Suggested an ultrasound ranging technique could detect underwater objects.

1915 - Langevin - developed RADAR (Radio Detection and Ranging) to detect submarines in WW1. By 1941 this was developed in the USA to detect airplanes.

Ultrasonic Detection - Acoustic Horns

Used to detect aircraft - Pre-Radar



World War 1

World War 2

History of Cardiac Ultrasound

The Industrial Development of Ultrasound

- 1937 - Sergei Sokolov – used ultrasound waves as a means of detecting flaws in metals.

- 1942 - Floyd Firestone – Metal Flaw Detecting device and measuring instrument.

History of Cardiac Ultrasound

The Non-Cardiac Development of Clinical Ultrasound

- 1941 - Karl Dussik. Austrian Neurophysicist
- Probably the first application of clinical diagnostic ultrasound to outline the ventricles of the brain.
- BUT - concluded that this was probably not a viable clinical tool due to sound attenuation and interfering reflective waves!!!

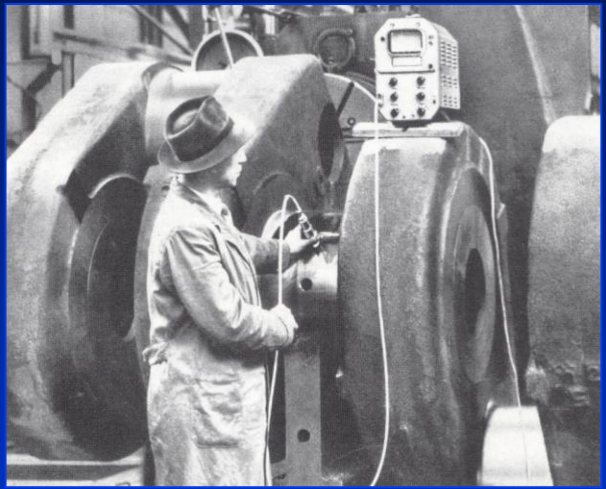
History of Cardiac Ultrasound

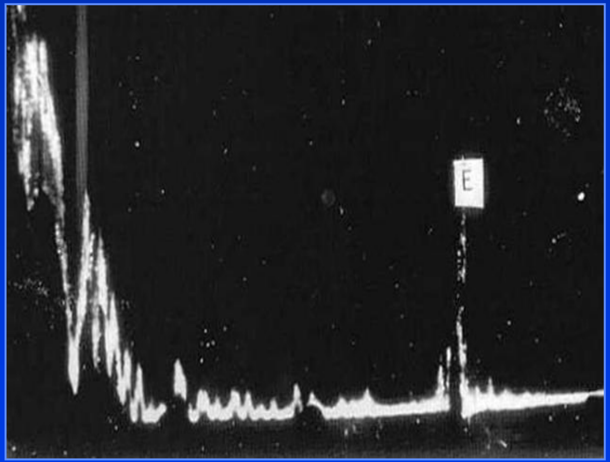
- 1946 - Wolf Dieter Keidel. German Physicist

- Used transmitted ultrasound to measure cyclical variations in cardiac volume. However, he could not make his method quantitative.
- However, both Dussik and Keidel subsequently concluded that, for theoretical reasons, reflected ultrasound could not be used as a diagnostic tool in the clinical setting!!

"The immense technical problems compared to the crude diagnostic possibilities render any work in this field hardly worthwhile"

Early Use of an Ultrasound Device to Detect Metal Flaws





Malmö, May 1953

Kockum's Shipbuilding Cie.
Malmö

The Siemens Reflectoscope

History of Cardiac Ultrasound

- 1953   Hertz and Edler
- Lund University and the Malmo Shipyards.
- Hertz read “Der Ultraschall” by Ludwig Bergman – a theoretical ultrasound textbook.
- Theorised that left atrial dimensions could be measured.
- Contacted Inge Edler whose clinical interest was mitral stenosis.
- They borrowed an ultrasonic reflectoscope from Kockums shipyard. Detected pulsatile cardiac signals!

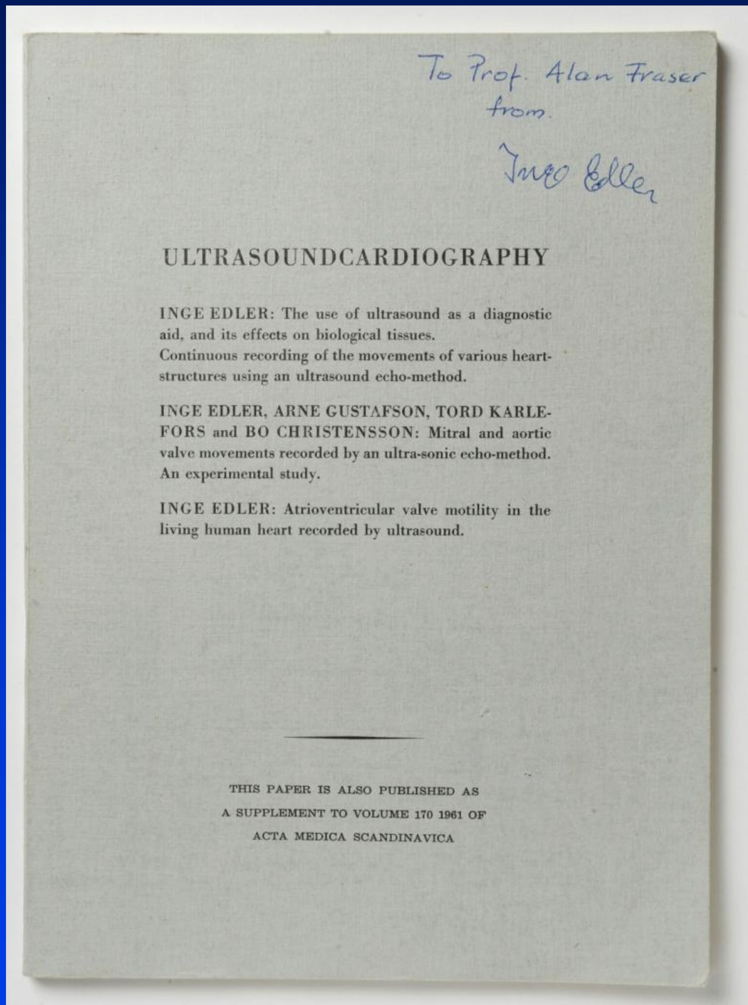
History of Cardiac Ultrasound

- Hertz's father, a Professor of Physics and Nobel Prize Winner was a Siemens Director.
- His uncle gave his name to the Hertz unit.
- Hertz visited Erlangen where Siemens were developing an advanced reflectoscope.
- 1954 After waterbath expts to validate the A-mode images Hertz and Edler proceeded to measure thickness of cavities and cardiac walls.
- Edler then developed M-mode Echocardiography.

Inge Edler 1911 - 2001

Edler I, Hertz H. The use of ultrasonic reflectoscope for the continuous recording of the movement of heart walls. Kungl Fysiografiska Sällskapets i Lund Förhandlingar 1954; 24: 40-58.

Hertz and Edler - M-Mode Echocardiography



To Prof. Alan Fraser
from
Inge Edler

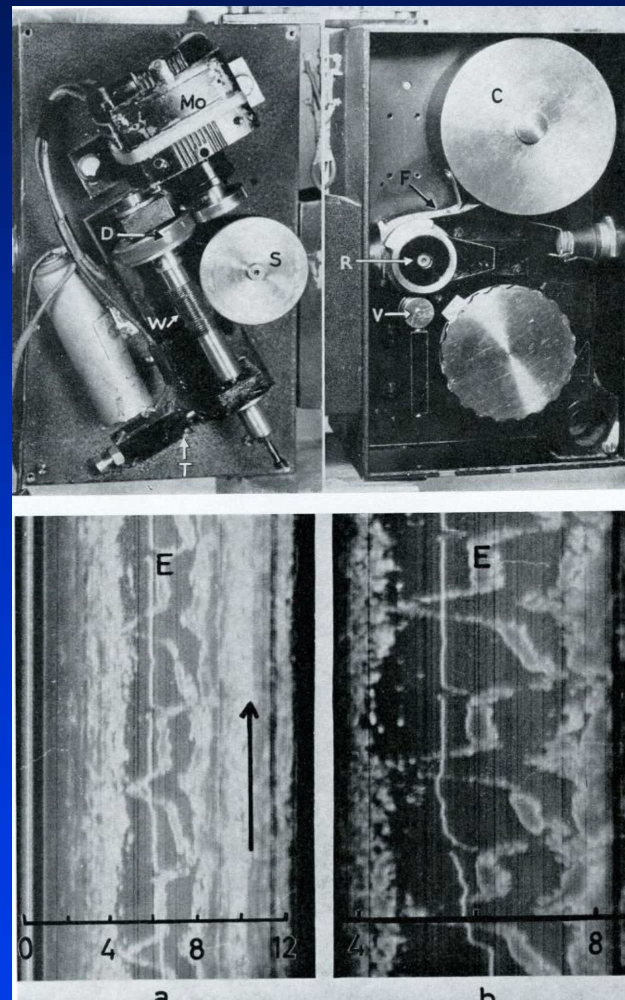
ULTRASOUNDCARDIOGRAPHY

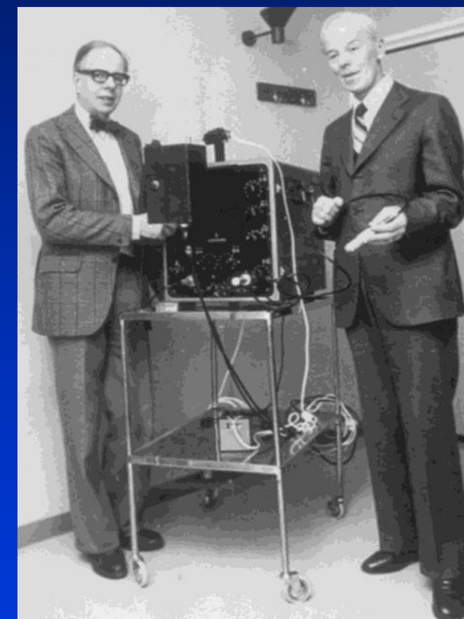
INGE EDLER: The use of ultrasound as a diagnostic aid, and its effects on biological tissues.
Continuous recording of the movements of various heart-structures using an ultrasound echo-method.

INGE EDLER, ARNE GUSTAFSON, TORD KARLEFORS and BO CHRISTENSSON: Mitral and aortic valve movements recorded by an ultra-sonic echo-method. An experimental study.

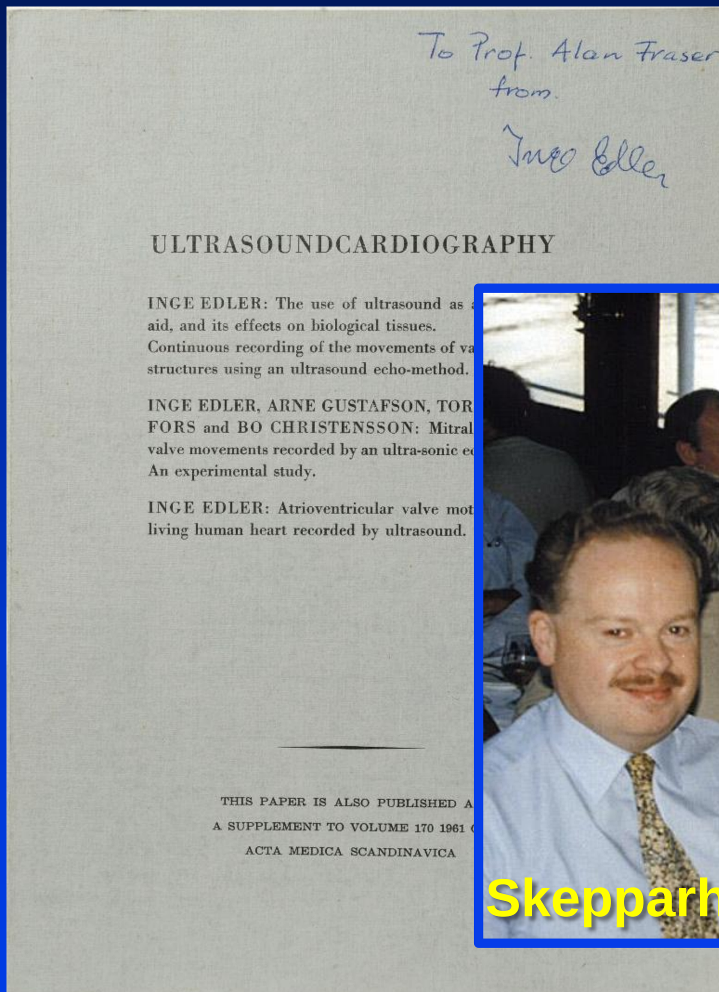
INGE EDLER: Atrioventricular valve motility in the living human heart recorded by ultrasound.

THIS PAPER IS ALSO PUBLISHED AS
A SUPPLEMENT TO VOLUME 170 1961 OF
ACTA MEDICA SCANDINAVICA





The First M-Mode Cardiac Ultrasound Recording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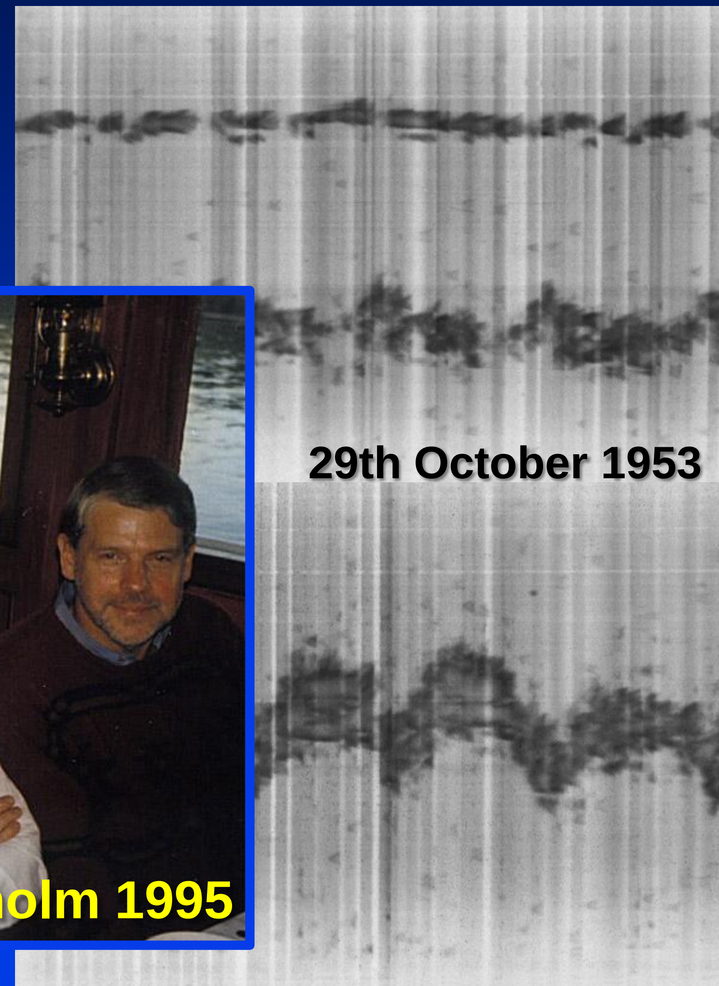
Skepparholmen, Stockholm 1995


29th October 1953

History of Cardiac Ultrasound

- **1954 - EDLER & HERTZ** ***- A + M-mode***
- **1977 - 2D + pulsed Doppler**
- **1970-75 - 2D-echo** ***(B-scan, linear, 2-D sector scanning)***
- **1982 - 2D + pulsed / CW Doppler.**
- **1982- 2-D Transoesophageal echo.**
- **1990-2015 - 3D-echo, Tissue Doppler**

The Role of Cardiology Publishing 1973-1985


Circulation

FRAME OF REFERENCE

Centennial Collection
Adult Congenital Heart Disease
M Dellborg 1397

Perspective
Fossil Fuels, Climate Change, and Cardiovascular Disease: A Call to Action
CG Solomon and PJ Landrigan 1400

Global Rounds
Global Rounds: Cardiovascular Care in Australia and New Zealand
S Zaman ... DP Chew 1402

ORIGINAL RESEARCH ARTICLES

Reduced Ejection Fraction in Elite Endurance Athletes: Clinical and Genetic Overlap With Dilated Cardiomyopathy
G Claessen ... on behalf of the Pro@Heart Consortium 1405

Editorial
Unraveling the Unsolved Mysteries of the Athletic Heart
WK Cornwell III and BD Levine 1416

Clonal Hematopoiesis of Indeterminate Potential With Loss of *Tet2* Enhances Risk for Atrial Fibrillation Through *Nlrp3* Inflammasome Activation
AE Lin ... BL Ebert 1419

ORIGINAL RESEARCH ARTICLES

Directed Differentiation of Human Induced Pluripotent Stem Cells to Heart Valve Cells
Z Cai ... N Dong 1435

Editorial
Empowering Valvular Heart Disease Research With Stem Cell–Derived Valve Cells
M Shen and JC Wu 1457

THE PULSE

From the *Circulation* Family
Highlights From the *Circulation* Family of Journals 1461

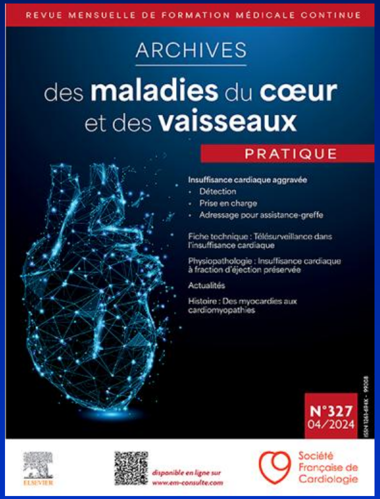
CORRESPONDENCE

Research Letters
Peripheral Oxygenation and Pulmonary Hemodynamics in Individuals With Fontan Circulation During 24-Hour High-Altitude Exposure Simulation
N Müller ... J Tank 1466

American Heart Association.

Volume 149, Number 18, April 30, 2024
ISSN 0009-7322
www.ahajournals.org/journal/circ

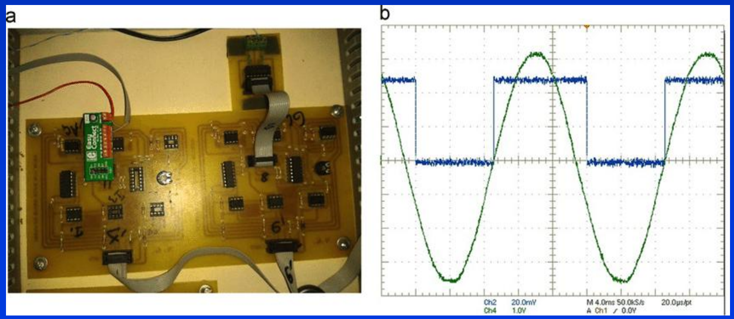
JACC
JOURNALS



英文誌「Journal of Medical Ultrasonics」の過去2年分掲載論文

Early Cardiac Doppler Pioneers 1957-75

- **In France – Kalmanson, Peronneau**
- **In UK – Wells, Light, Tunstall-Pedoe**
- **In USA – Baker, Gramiak, Shah**
- **In Japan – Satomura 1957!, Yoshida, Kato**



Most early Doppler devices were both directional and range-limited Zero Crossing Devices. High velocities not resolved.

History of Cardiac Ultrasound

The Japanese Doppler Contribution

- 1842 Christian Doppler -The Doppler Effect.
- 1956 Shigeo Satomura - an Osaka Physicist publishes paper on blood flow in limbs and the eye using a mechanical vibration measurement. Essentially Doppler Echocardiography.
- 1957 Satomura, Nimura and Yoshida. Ultrasonic Doppler for inspection of Cardiac Function.
- 1958 Satomura et al. Developed Low pass filters. Simultaneous recording of phono and ECG.
- 1962 Kato et al. verified phase shift proportional to velocity. But no directional information.
- 1966 Kato and Izumi develop a directional Doppler Flow Meter.

History of Cardiac Ultrasound

The French Contribution

- 1961 Franklin et al. Peripheral arterial CW.
- 1965 George and Pourcelot. Non-directional CW.
- 1968 Bechimol. Catheter tip CW evaluation of venous and coronary flow.
- BUT all were non directional and were discredited as clinical tools.
- 1968 Kalmanson et al. introduced resolved flow velocity recordings.

History of Cardiac Ultrasound

The American Role

- 1952. Wild and Reid examine excised hearts ultrasonically.
- 1963 Reid and Joyner. 1st US article on mitral stenosis.
- 1963 Feigenbaum borrowed neurologists reflectoscope and identified a pericardial effusion.
- 1968 Feigenbaum and Dodge. M-mode wall thickness and cavity dimensions. Calls technique “Echocardiography”.
- 1968 First Indianapolis Echo course. Inge Edler attends!
- 1970 Eggleton mounts ultrasound crystal on rotating electronic toothbrush to produce first commercial 2-D echo.
- 1973 S.L.Johnson develops the range-gated Duplex Scanner.

Trondheim Doppler Development 1970-76

1968 NTSU founded in Trondheim – Alf Brubakk first Clinical Academic appt.

1970 Rune Aaslid - his friend- developed "Jenny" computer to model CVS flow at the newly created Trondheim NTNU

Rune Aaslid

Bjorn Angelsen 1973 - develops PEDOF Doppler system in Trondheim – gets first signals

Asslid meets Holen in Oslo and shows him PEDOF system

Jarle Holen – Boeing aircraft engineer - is sure cardiac pressure gradients can be measured

Trondheim Doppler Development 1970-76

1974/75 Holen produces equation showing the relationship of pressure and velocity thus allowing the calculation of pressure gradients.

Asslid discusses the Holen equation with Anglesen on return to Trondheim.

Angelsen modifies PEDOF system to combine PW/CW and simplifies the Holen equation

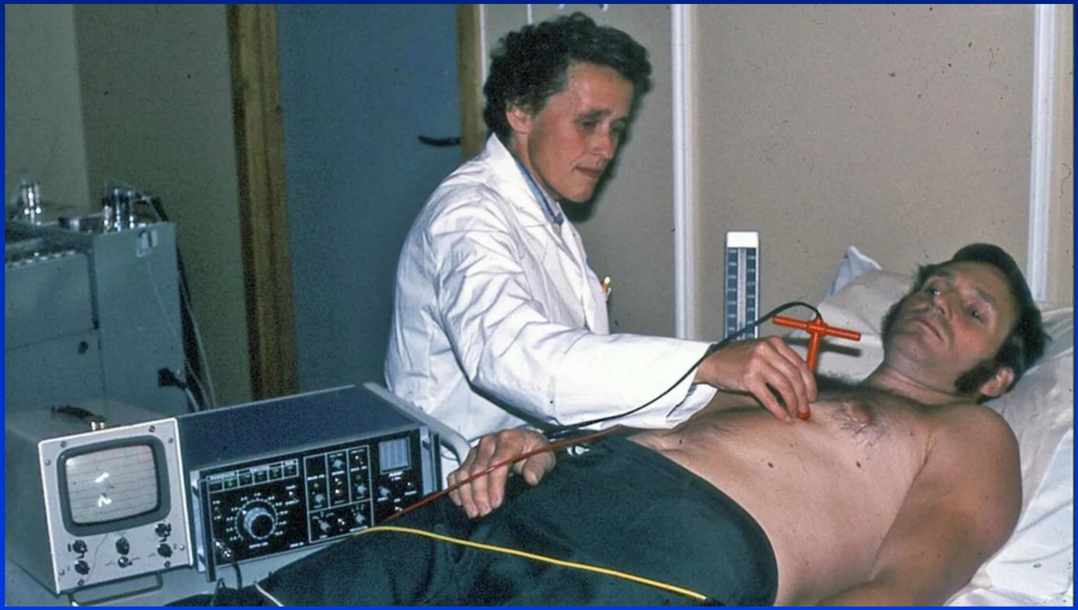
1976 – Angelsen and Kjell Kristoffersen build 10 PEDOF systems at NTNU for clinical trial.

1976- PEDOF trialed by - Liv Hatle – Alf Brubakk - Ingmar Wallentin – Dan Tunstall-Pedoe

1981 – First commercial implementation of PEDOF in IREX echo system.

Duplex echocardiography now possible

Liv Hatle - Scanning with the Trondheim PEDOF Doppler System



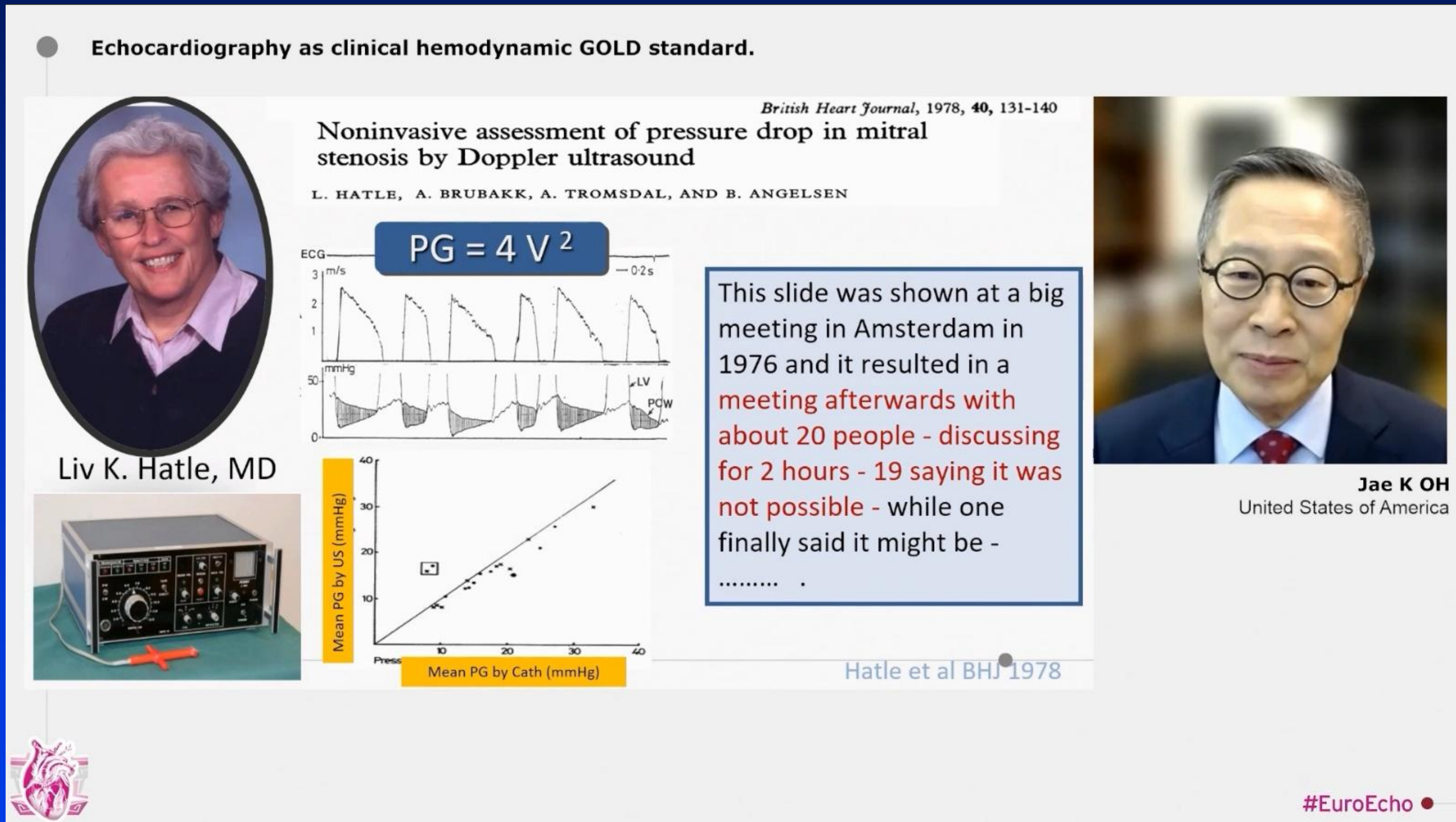
$\Delta P = 4 * (v_2 - v_1)^2$

If v1 < 1m/s

$\Delta P = 4 * v^2$

Holen – Hatle – Angelsen Modification

1976 – Controversy!



Liv Hatle - Original Scientific Contributions

Mitral Stenosis

Aortic Stenosis

Valve Regurgitation

Pulmonary Pressure / Resistance

Hypertrophic Cardiomyopathy

Congenital Heart Disease

Trondheim

1978-83

Diastolic Dysfunction

Constriction / Restriction

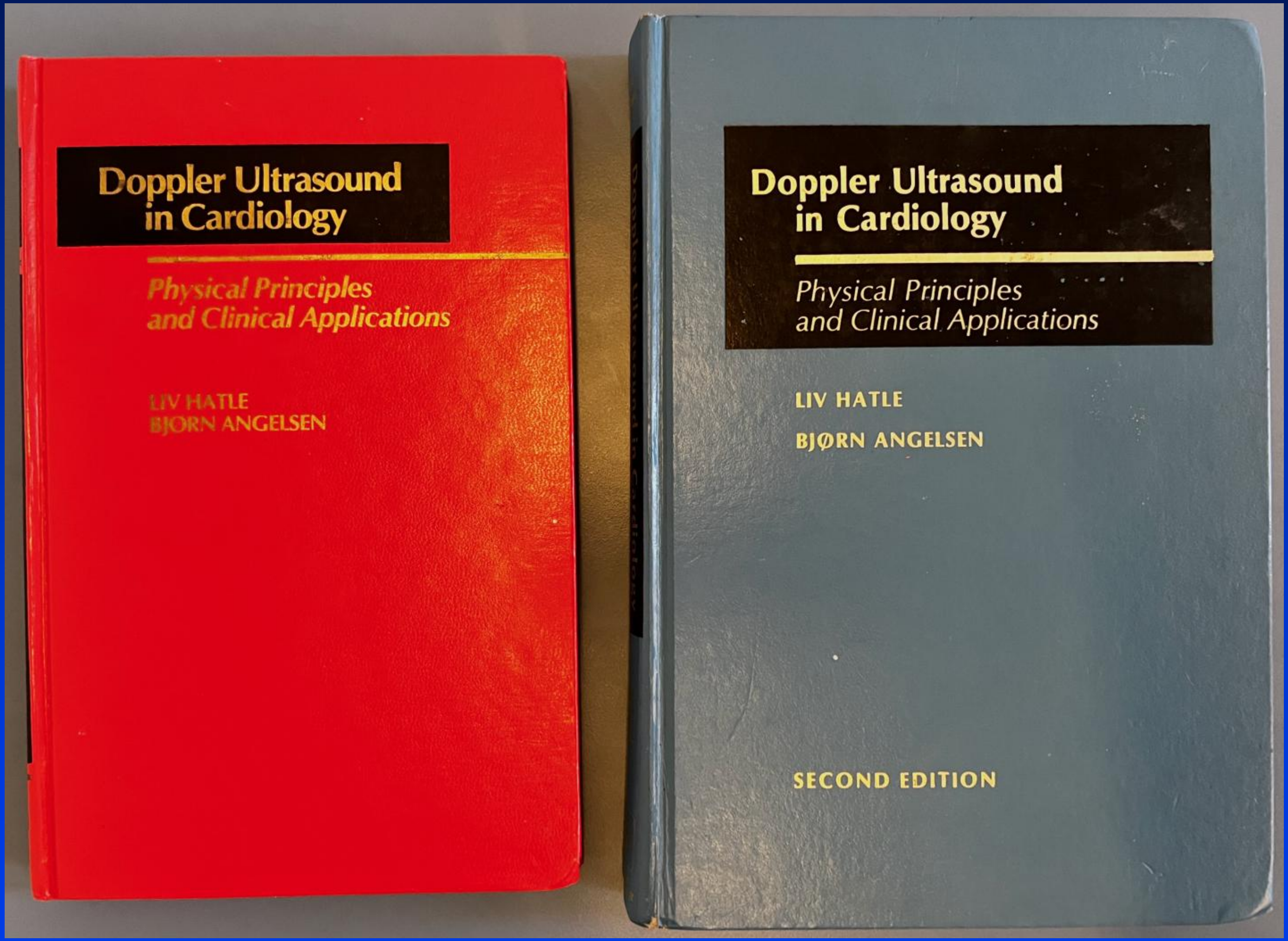
Cardiac Amyloidosis

Prosthetic Valve Function

Mayo / Stanford

1984-90

The Textbook - 1985



Cardiac Scanner Development

- 1974 / 76. Duplex scanners introduced.
- Both phased array (Toshiba / Aloka) and mechanical probes(ATL and Vingmed).
- Mechanical best suited to Paediatric Cardiology. High structure resolution.
- Full description of all complex congenital anomalies by 1981.
- Adult 2-D phased array development lagged behind due to transducer / display limitations.

History of Paediatric Echo

1967 -1995

- L. B.Ultan 1967 Echo in CHD-Preliminary Observations.
- Lundstrom 1971- M-Mode
- Gramiak 1973- M-Mode
- Van Praag - Terminology 1977
- Tynan, Becker, Anderson. Terminology 1979
- Rigby et al 1981 UVH Morphology – Correlative 2-D Echo
- Hatle - VSD Doppler 1981
- Stumper 1900 - Paediatric 2-D TEE

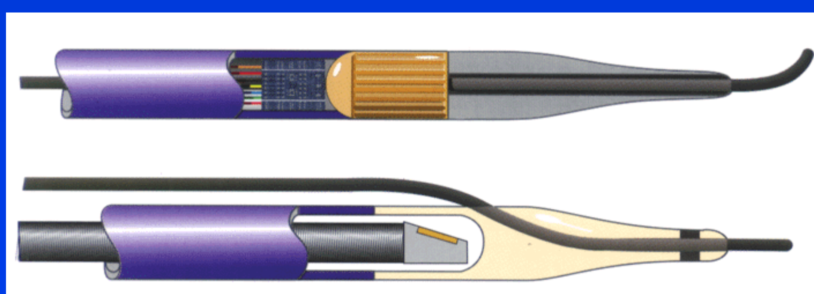
Transducer Development – 1980 - 2024

- phased array: 1D array of crystals
- mechanical: internal ‘wobbling’ of 1 crystal

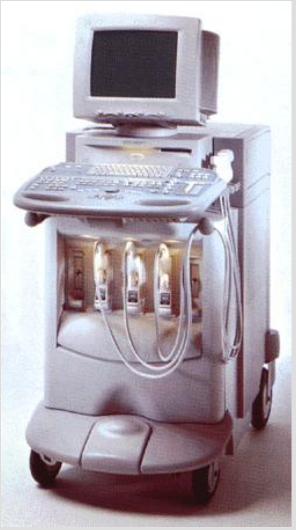
linear array

sector array

- transesophageal
- intravascular
- transrectal
- transvaginal



Scanner - Development



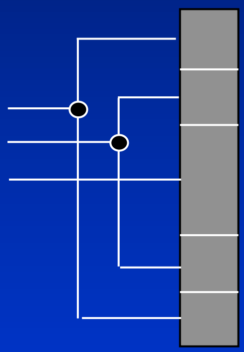
Portable Ultrasound Systems

Are they just smaller versions of the current generation of clinical cardiac scanners ?

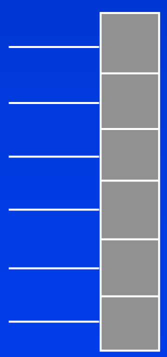
Further Transducer Technology - Materials

Current clinical transducer: 1.5D; soon: 1.75D

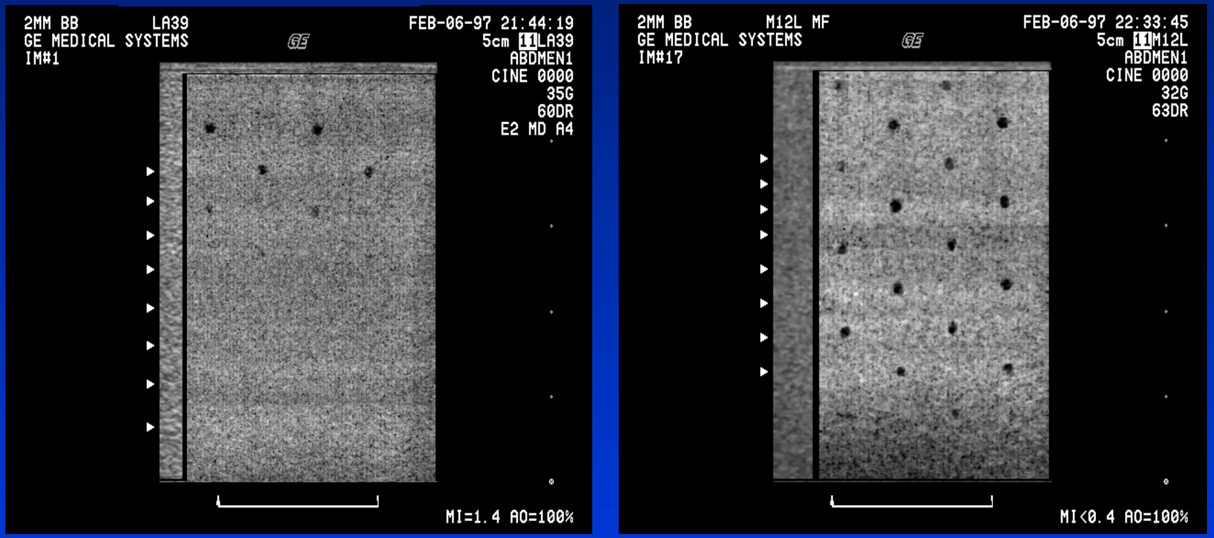
1.5D



1.75D



Single Row | Multi Row



Phantom with 2 mm Spherical Cysts

Courtesy: Kai Thomenius (GE)

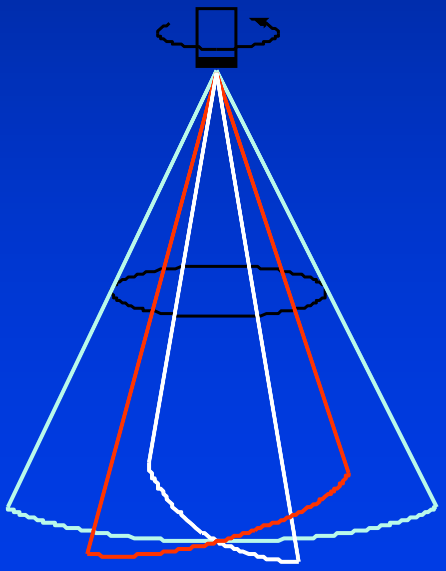
→ **128x10 elements already tested**

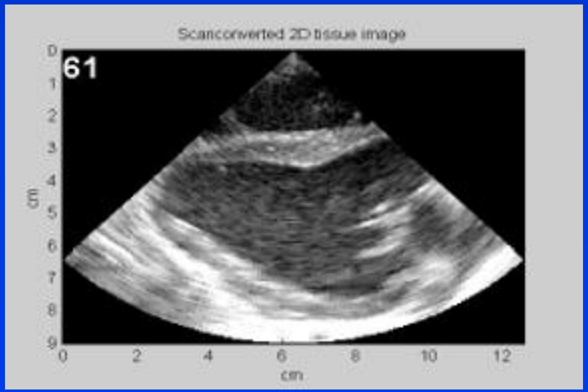
Is this sufficient?

3D Imaging Technology

- 1D phased arrays + rotating holder
- 1D fast rotation phased array
- 2D arrays

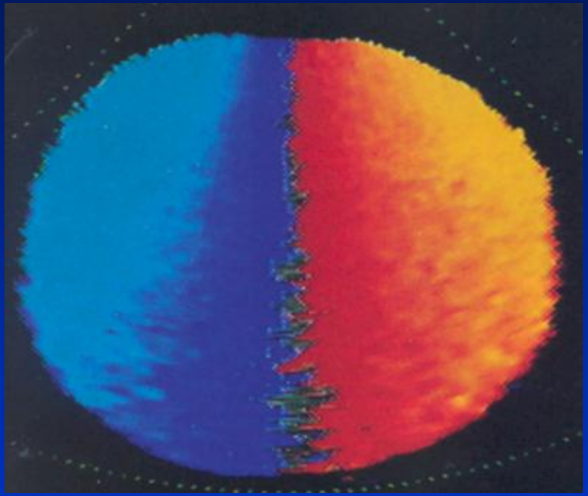
Lancee, C. et al., Thoraxcentre Rotterdam

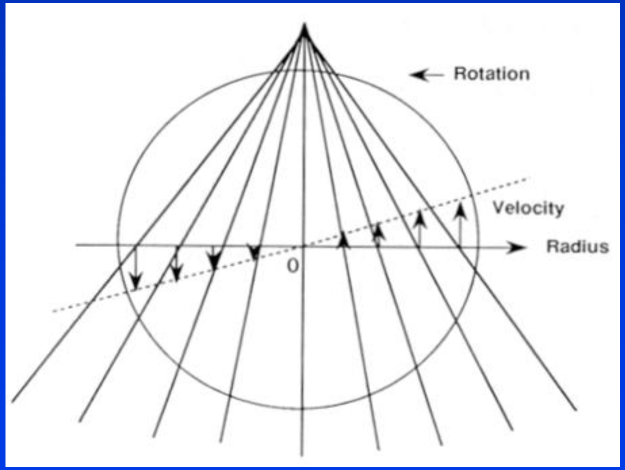


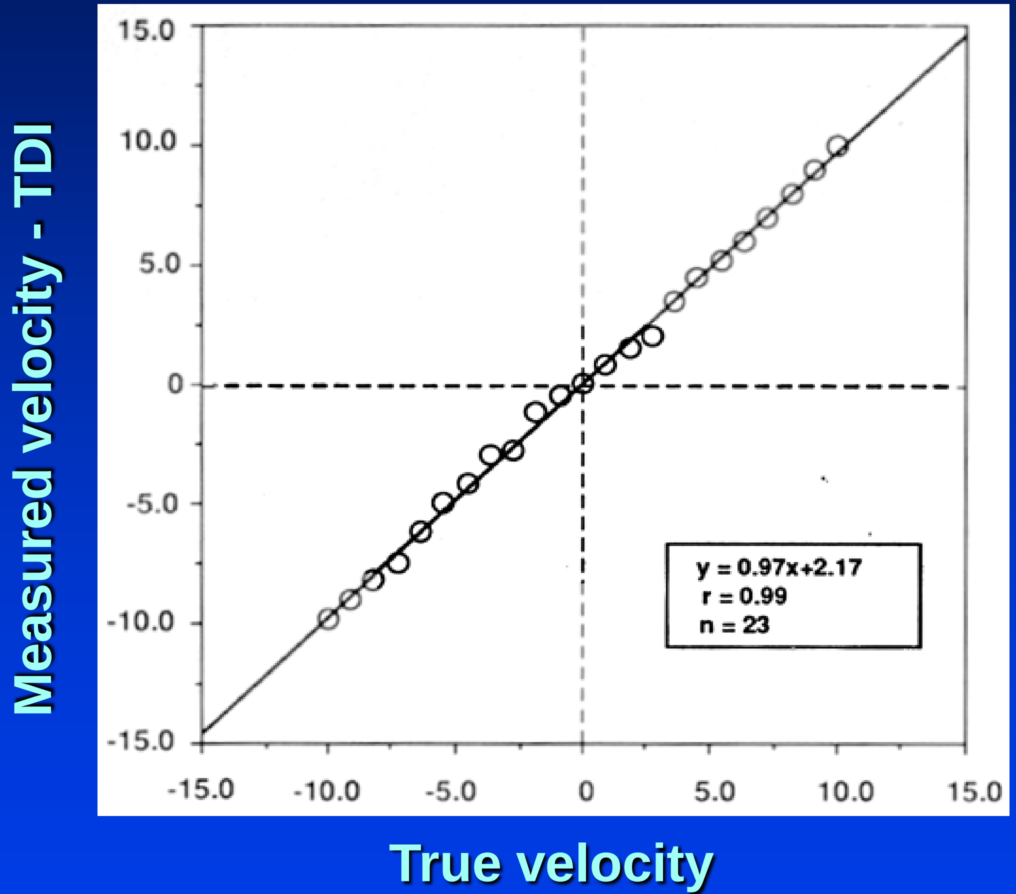


BUT: frame rate !?!

Myocardial Doppler - 1991

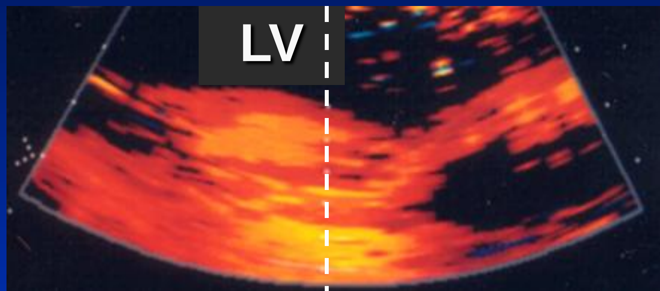




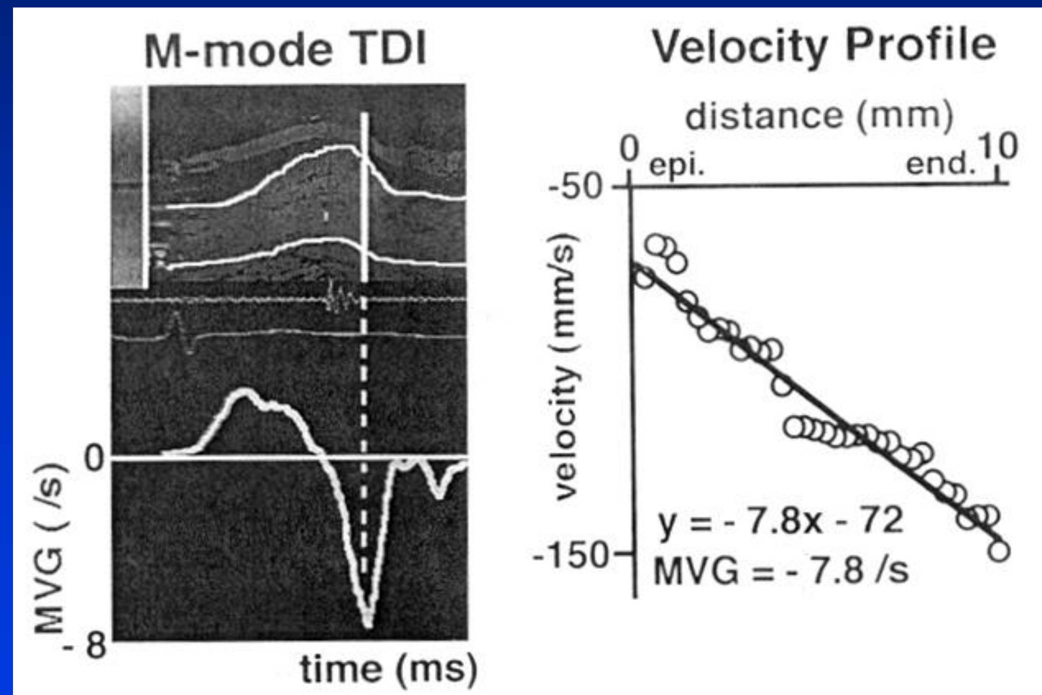


Edinburgh 1991

Myocardial Velocity Gradient

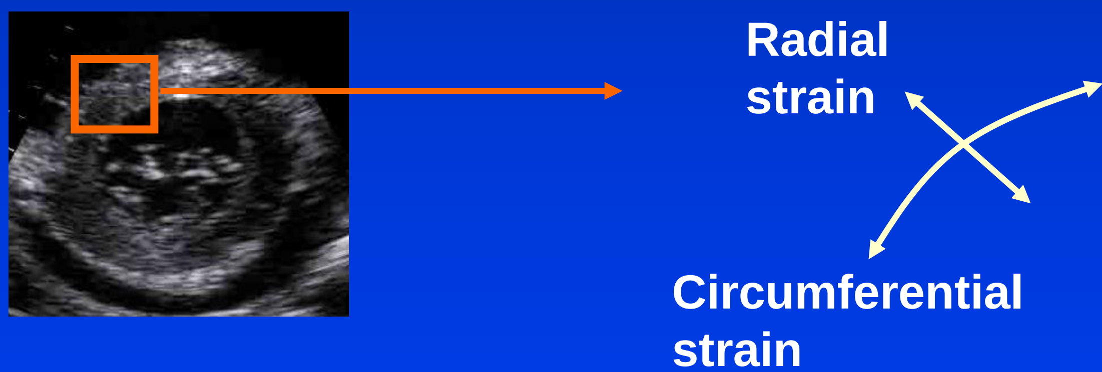


Strain / Strain Rate Imaging



Edinburgh 1991

2D Strain Imaging

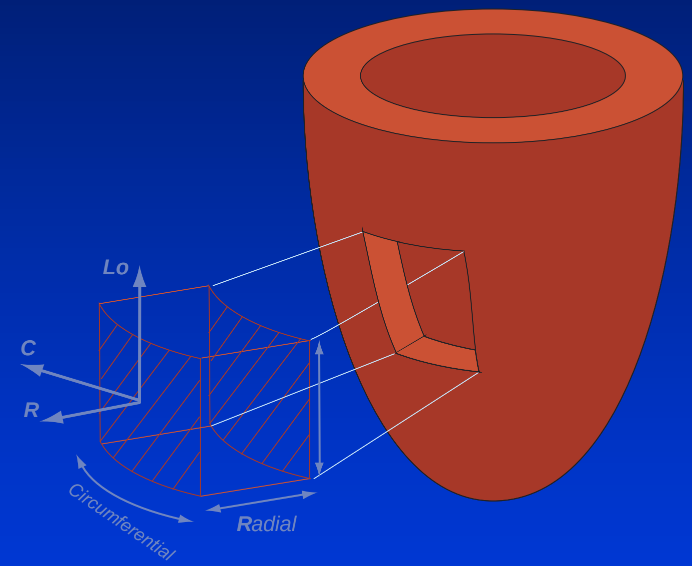


Real Time Resolved 4-D Echo
Huge Data Management Requirements!

- *Sufficient spatial and temporal resolution*
  - 500 samples/scanline
  - 100 beams/slice
  - 100 slices (90 *angles* (every 2°))
  - 150 Hz framerate

= 10.000 scanlines @ 150 Hz

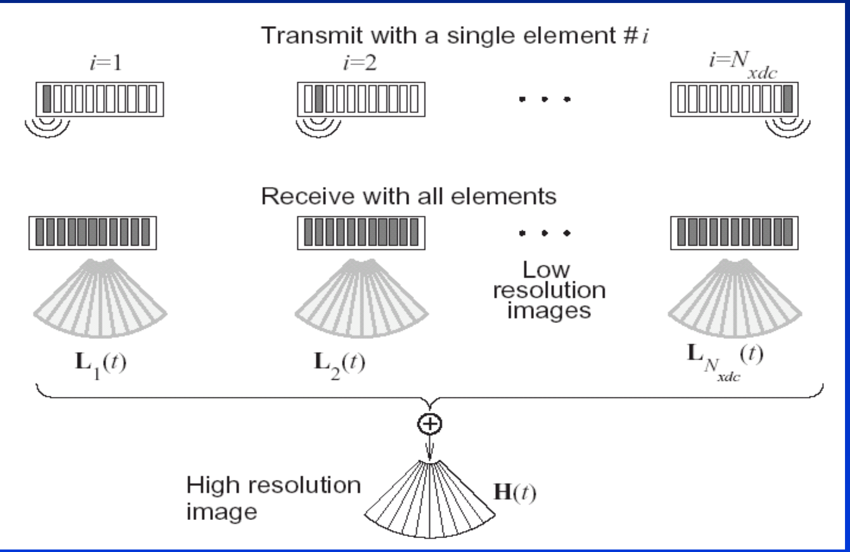
= 1.500.000 scanlines/s



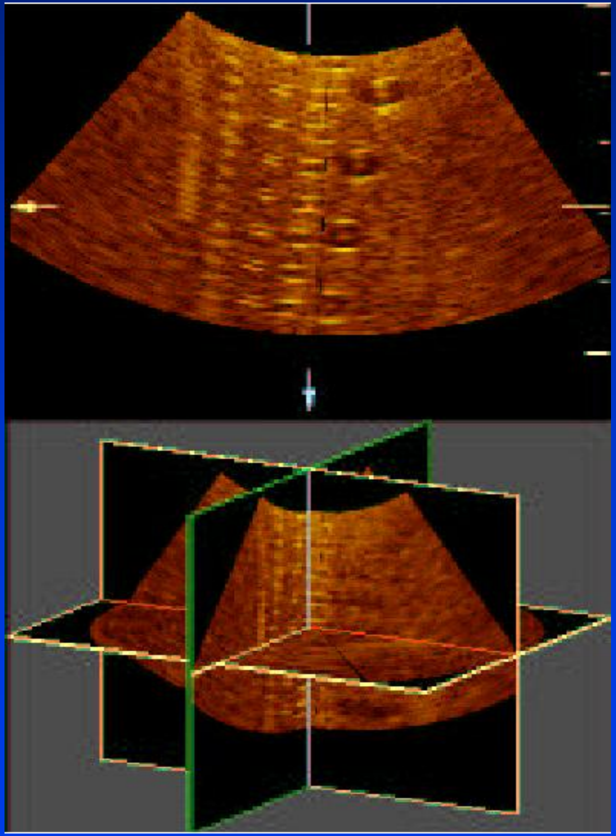
- *Amount of data (1 view -1 Heart cycle)*
  - = 750 MB non-scanconverted
  - = 18 GB scanconverted !!!!

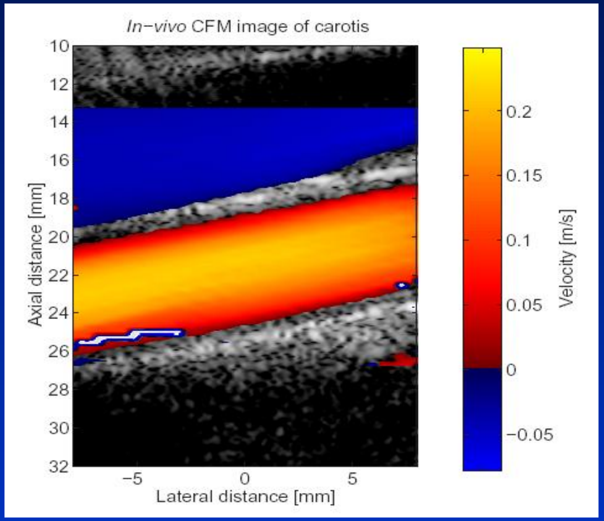
Synthetic Aperture Imaging?

Fundamentally different way of beamforming



3D imaging





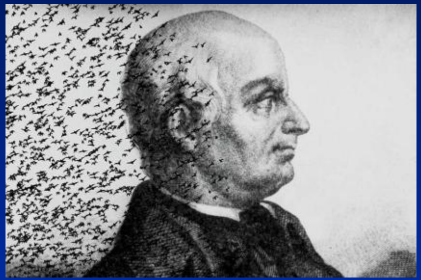
2D flow

Very High Frame Rates

Courtesy: J.A. Jensen, Lyngby, Denmark

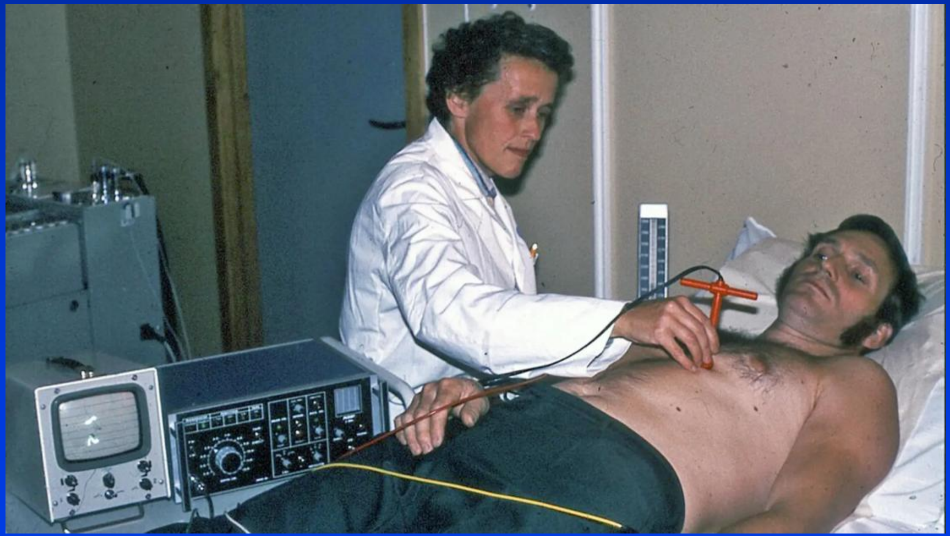
History of Cardiac Ultrasound

An Amazing Story 1793-2020



Spallanzani 1793

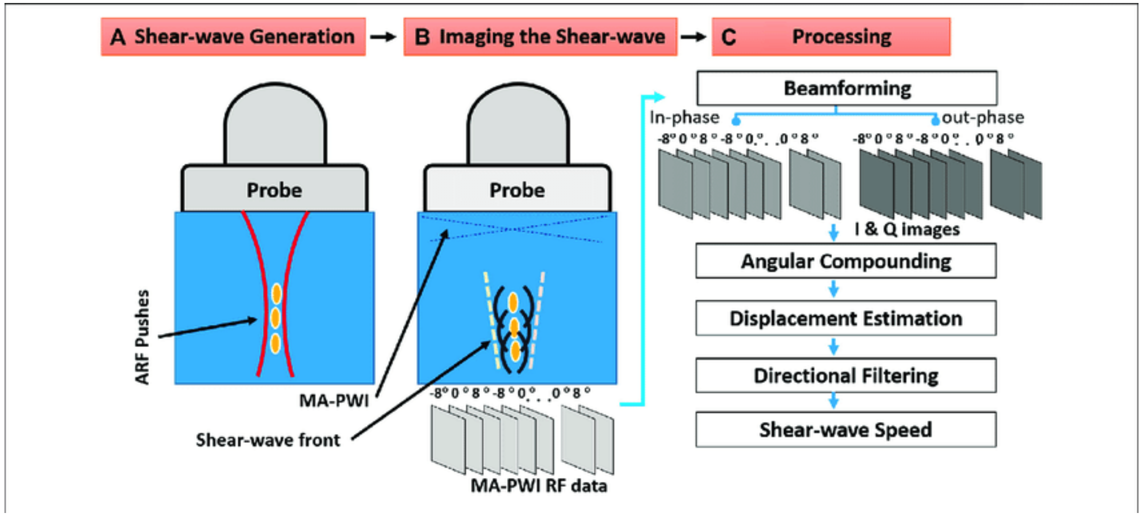
Edler and Herz 1993



Liv Hatle / Holen /Angelsen 1975

The Future?

Ultra High Frame Rate Deformation Imaging



Shear Wave Elastography

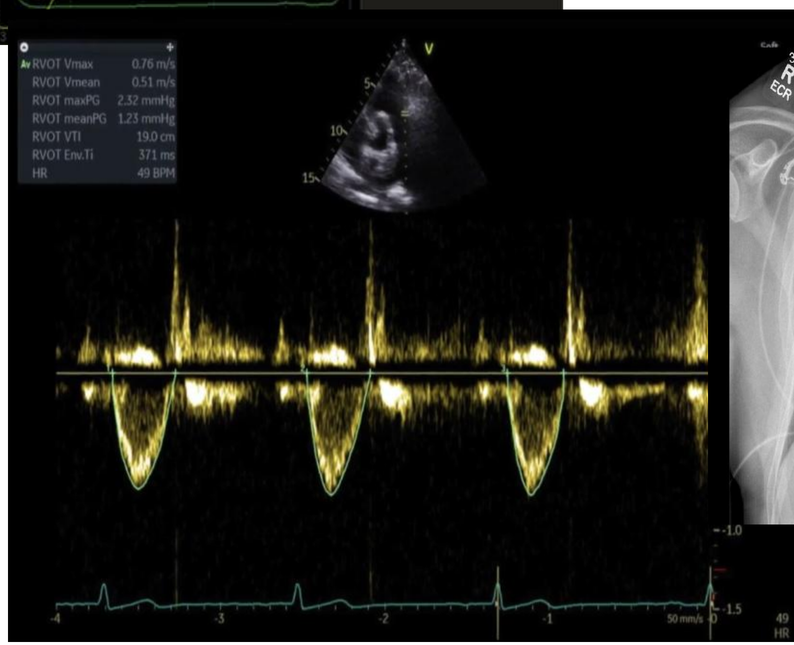
FPS in excess of 4000 fps.

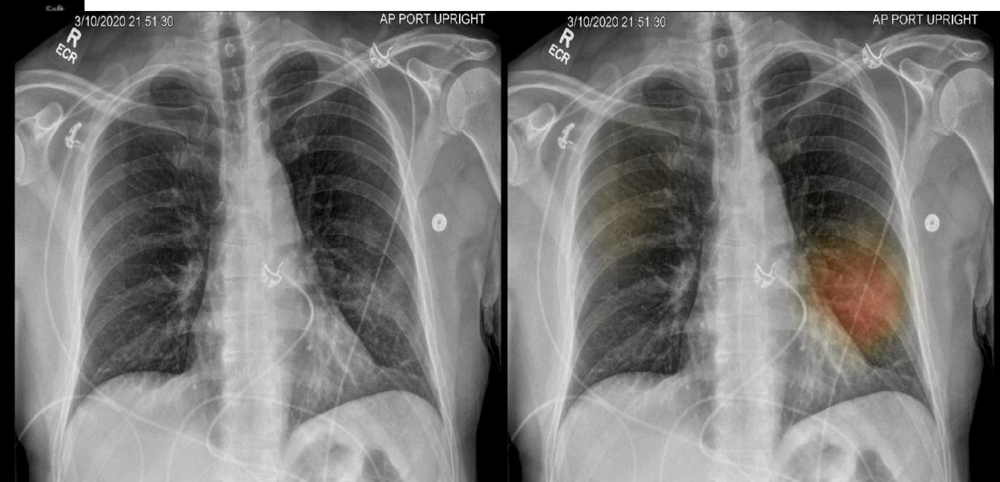
Machine Learning is already in our machines for feature extraction!

Philips

Infervision

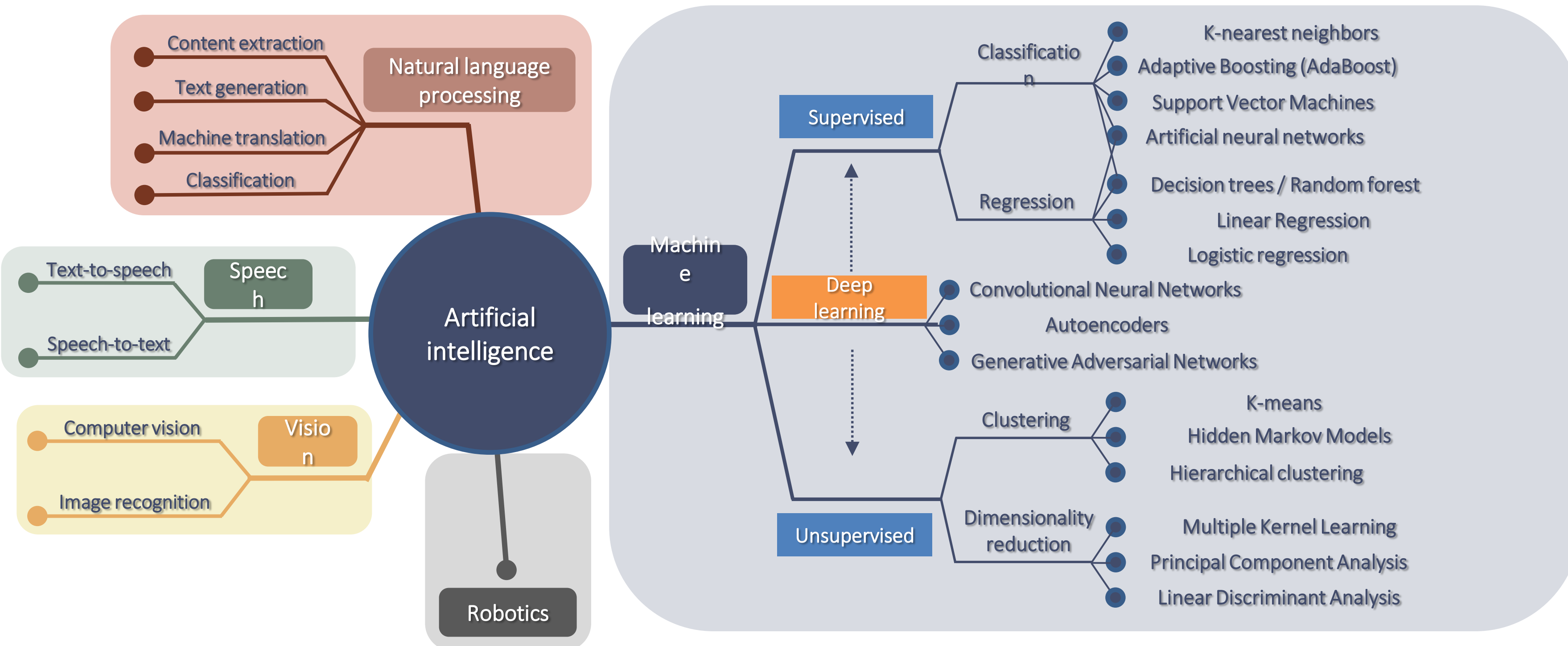
GE





UC San Diego

Digital Health: Artificial Intelligence and Machine Learning



Loncaric F, Revista Española de Cardiología 2021

AI & Deep Learning surpass human performance in tasks thought impossible for a machine

Playing *Go*

AlphaGo

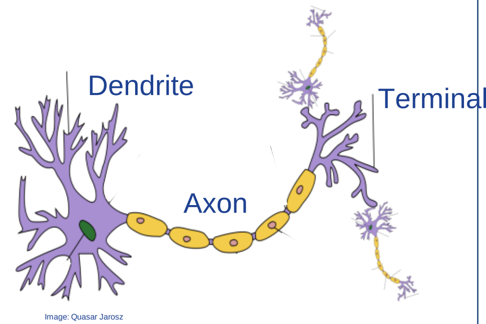
5:0
vs Fan Hui
(Oct. 2015)

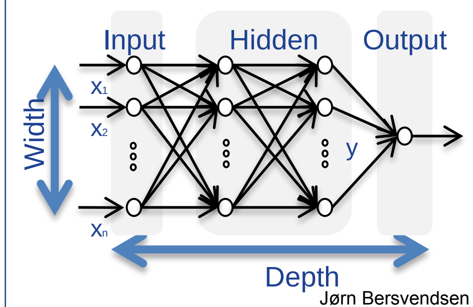
4:1
vs Sedol Lee
(Mar. 2016)

Interpreting text – Stanford reading comprehension test

Alibaba beats humans on 01/2018

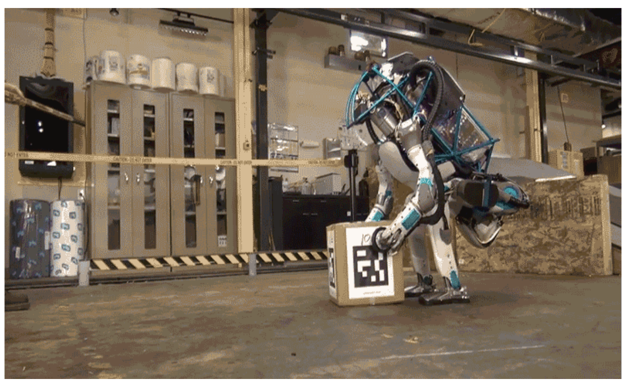
CIO.com.au



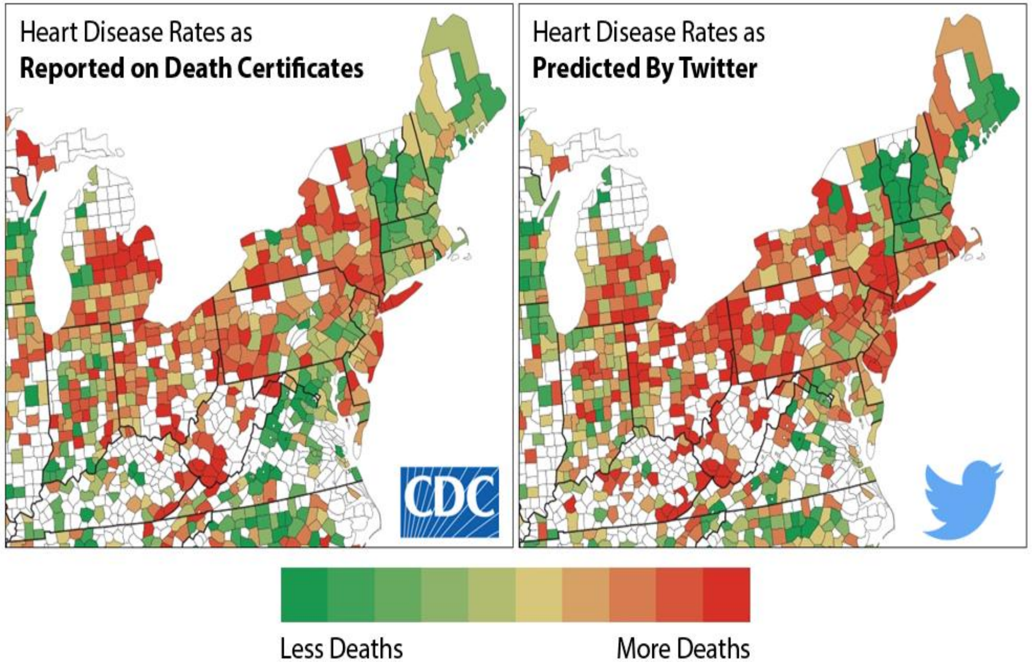


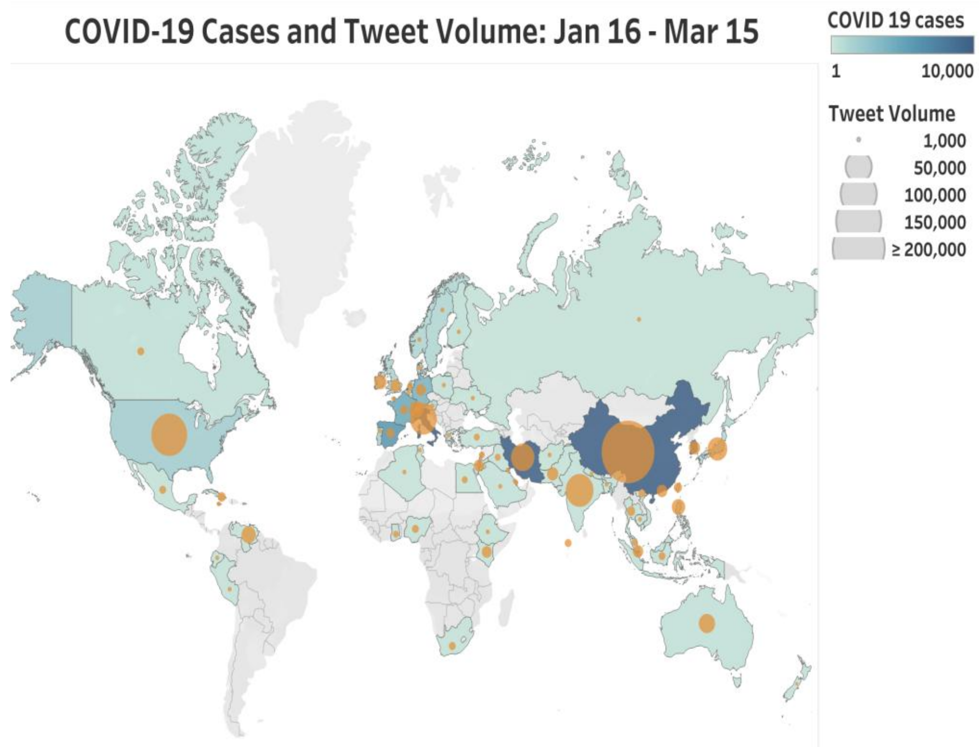
Artificial Neural Networks *Deep Learning*

Robots with similar/improved dynamics compared to humans/mammals



The Power of Machine Learning
Hidden Associations





Eichstaedt JC, Psychological Science 2015

Singh L, arXiv:2003.13907v1, 2020

It needs interpretation incorporating domain knowledge !!
(= you can't get rid of the expert)