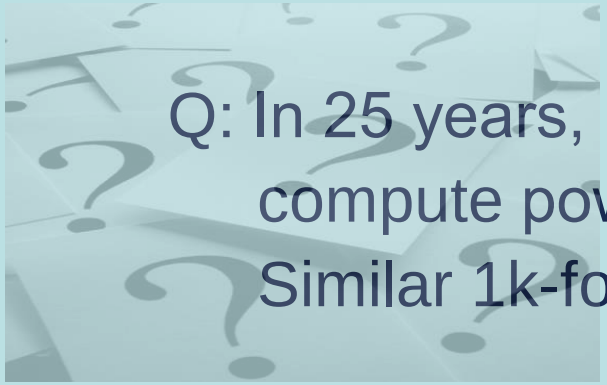

KATHOLIEKE UNIVERSITEIT
LEUVEN
From Great Compute Power to Super Signal Processing Applications
The Bridge's Silver Jubilee
Marc Moonen
Stadius Center for Dynamical Systems, Signal Processing and Data Analytics



Outline

- Introduction: The SVD (*) Prophecy
- 25 Years of SVD Applications
  - The Early Years
  - SVD Comes of Age
  - Current & Future SVD's



Q: In 25 years, 1k…10k-fold increase in compute power (Moore's law). Similar 1k-fold increase in SVD applications?

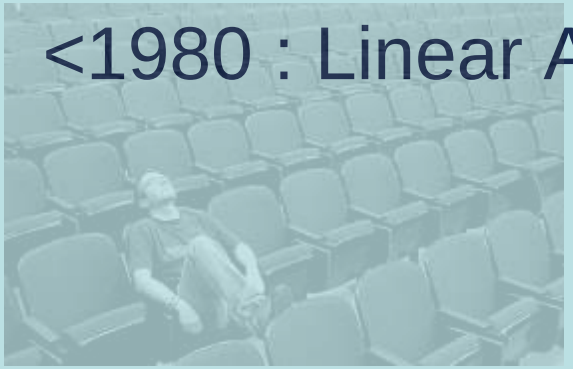
- Conclusions

(*) Singular Value Decomposition



Introduction: The SVD Prophecy

- <1980 : Linear Algebra @ESAT

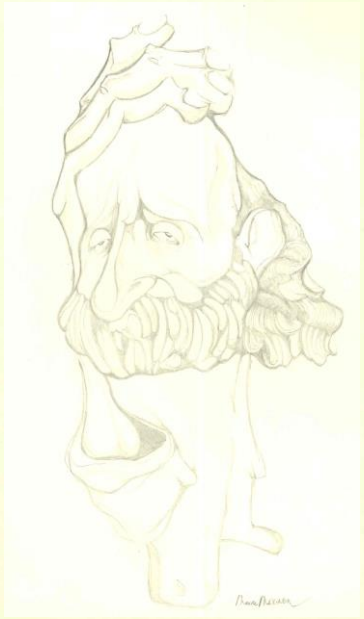


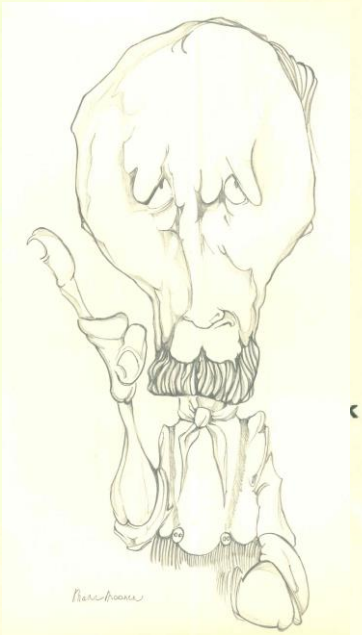
KATHOLIEKE UNIVERSITEIT TE LEUVEN

HOGERE ALGEBRA











Introduction: The SVD Prophecy





Introduction: The SVD Prophecy

- Le nouveau Linear Algebra est arrivé…



ALGEBRA EN ANALYTISCHE MEETKUNDE VOOR INGENIEURS

Nota's bij de cursus "Hogere algebra en analytische meetkunde (algebraisch deel)"
1e kandidatuur burgerlijk ingenieur(algemene richting en architectuur) en bij de cursus "Hogere algebra"
overgangsjaar industrieel ingenieurs
Academiejaar 1988-89

Prof. J. VANDEWALLE m.m.v. Prof. A. BULTHEEL

deel 2

VLAAMSE TECHNISCHE KRING

GROENVELDLAAN 1/50 3030 HEVERLEE
Tel 016-203297



Introduction: The SVD Prophecy

- Le nouveau Linear Algebra est arrivé…
  …with Singular Value Decomposition (SVD)

Stelling 3.7.10 *Iedere reële $m \times n$ matrix $\mathbf{A}$ van rang r kan geschreven worden als het produkt van 3 matrices*

$$\mathbf{A} = \mathbf{U}\Sigma\mathbf{V}^T \tag{3.7.82}$$

waarin $\mathbf{U}$ een $m \times m$ orthogonale matrix is en $\mathbf{V}$ een $n \times n$ orthogonale matrix is en Σ een $m \times n$ pseudo-diagonale matrix



$$\Sigma = \begin{bmatrix} \sigma_1 & & & \\ & \sigma_2 & & \\ & & \ddots & \\ & & & \sigma_r \end{bmatrix}. \tag{3.7.83}$$

m m singuliere waarden genoemd op de diagonaal en alle andere elewaarden zijn geordend van groot naar klein nl.

$$\sigma_1 \geq \sigma_2 \geq \cdots \geq \sigma_r > 0 \tag{3.7.84}$$

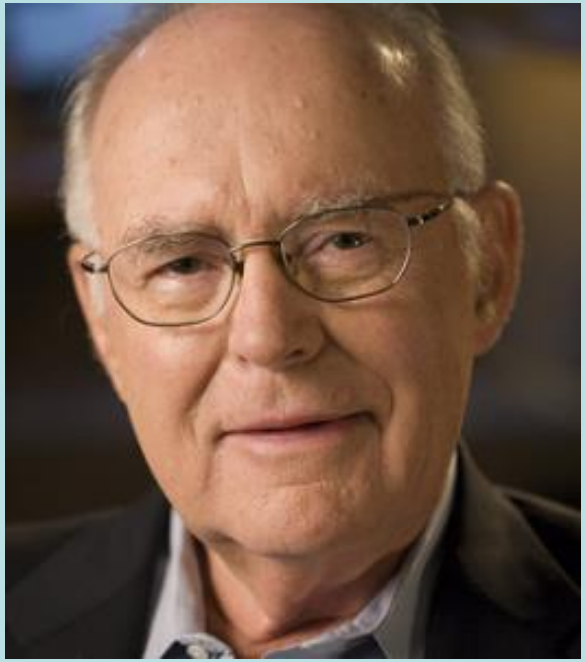
De ...n $\mathbf{U}$ zijn de linker singuliere vectoren en de kolommen $\mathbf{V_1} \ldots \mathbf{V_n}$ van $\mathbf{V}$ zijn de rechter singuliere vectoren.

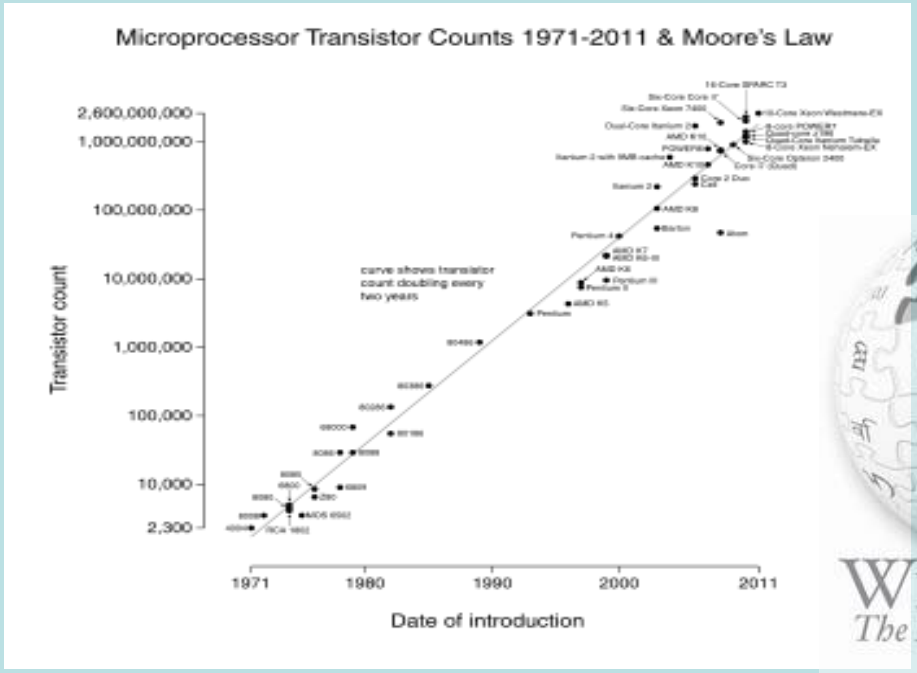


Introduction: The SVD Prophecy

Moore's Law OR

how overall processing power for computers will double every two years





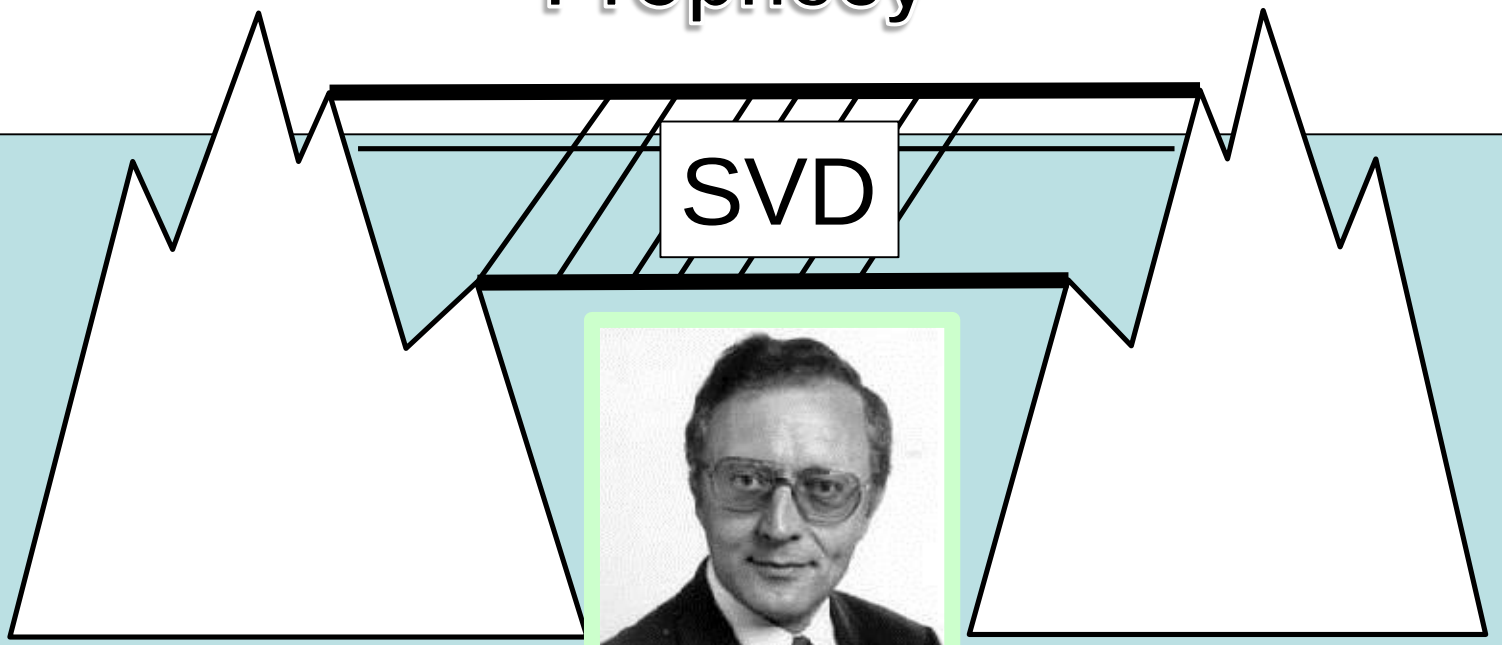


Moore's law is the observation that, over the history of computing hardware, the number of transistors on integrated circuits doubles approximately every two years. (…)
The law is named after Intel co-founder Gordon E. Moore, who described the trend in his 1965 paper (...).



Introduction: The SVD Prophecy

The Joos Vandewalle
'SVD Bridge'
Prophecy





Introduction: The SVD Prophecy

Now 25 years later…

The Bridge's Silver Jubilee

Would the SVD prophecy not deserve
a Wikipedia page, too?





Outline

- Introduction: The SVD Prophecy

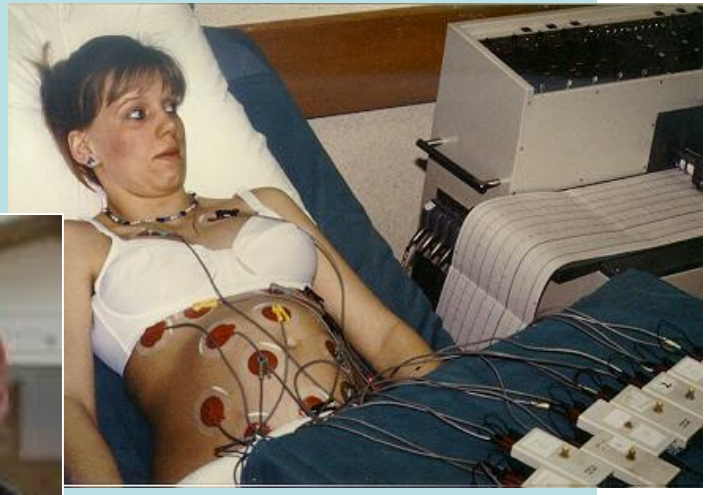
- 25 Years of SVD Applications (*)
  - The Early Years
  - SVD Comes of Age
  - Current & Future SVD's

- Conclusions

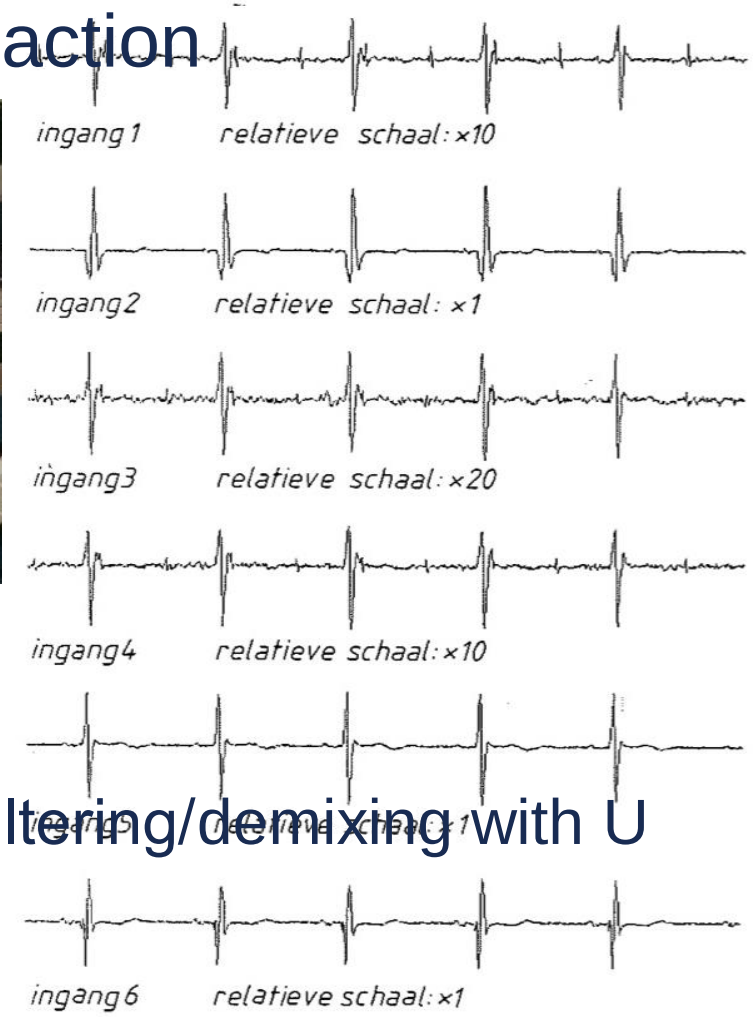
(*) pruned/ego-centric account

25 Years of SVD Applications
The Early Years

- SVD-based Fetal ECG Extraction







Procedure: Data Matrix = U.S.V', filtering/demixing with U

[1] J.Vanderschoot, et al., "An application of SVD to the extraction of weak bioelectric signal", Revue HF, Vol XII, 1983



25 Years of SVD Applications

The Early Years

- SVD-based Fetal ECG Extraction

SIGNAALVERWERKINGSEENHEID
VOOR DE EXTRACTIE VAN
HET FOETAAL ELECTROCARDIOGRAM 1


Jan Swevers


Marc Moonen

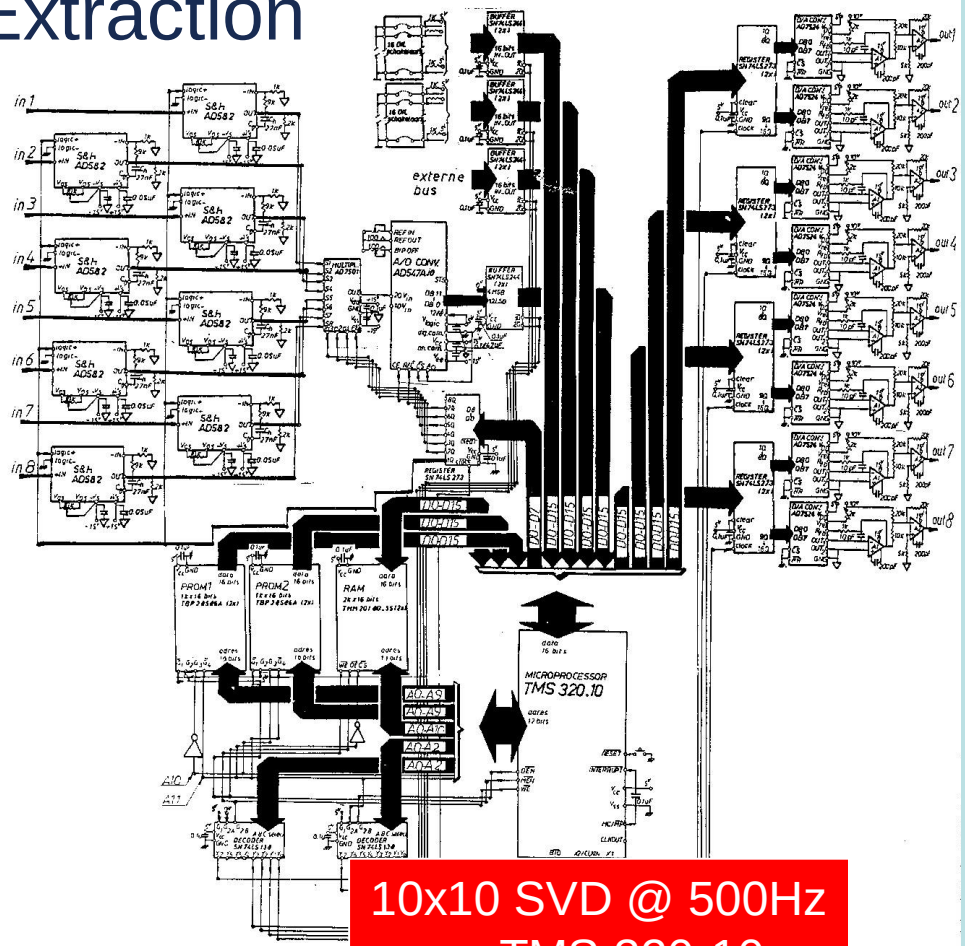
Promotoren
Prof. Dr. Ir. J. VANDEWALLE
Prof. Dr. Ir. W. SANSEN
Prof. Dr. G. VANTRAPPEN

Eindverhandeling aangeboden tot
het bekomen van de graad
Burgerlijk Electrotechnisch
werktuigkundig ingenieur
richting electronica
(regeltechniek)

door

Marc MOONEN
Jan SWEVERS

JULI 1986



figuur 25

10x10 SVD @ 500Hz
on TMS 320-10

approx 0,1M ops/sec



25 Years of SVD Applications

The Early Years

- SVD Workshops / NATO-ASI's / TLS Workshops

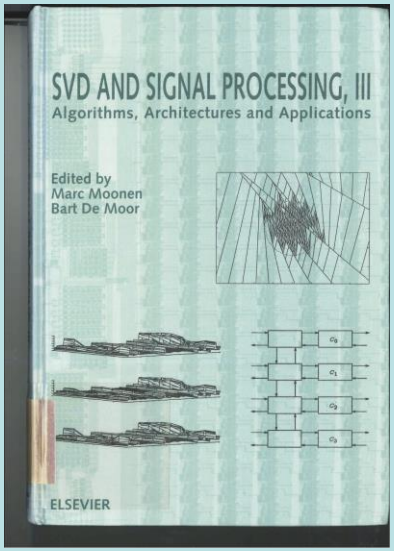
Les Houches, France, 1987

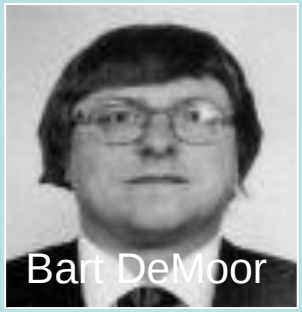


Rhode Island, USA, 1990



Leuven, Belgium 1994

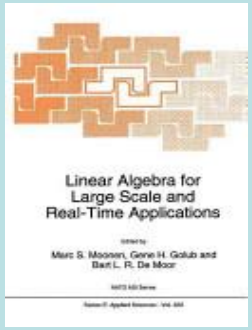


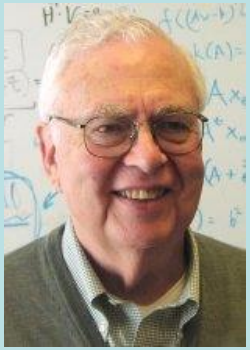


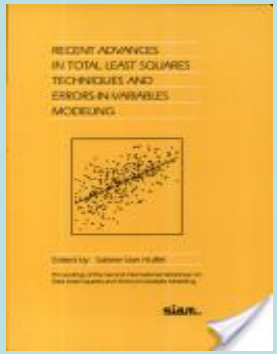


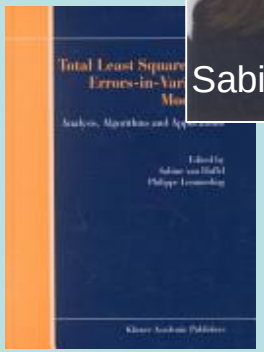














25 Years of SVD Applications

The Early Years

Dr.SVD versus SVD-HQ

STANFORD UNIVERSITY STANFORD, CALIFORNIA 94305-2095

Dear Marc :

I was very pleased to hear you will be attending several conferences in California this summer. I would be very pleased if you could spend some time with our Scientific Computing / Computational Mathematics group during the summmer when you are here. We can provide you with desk space, computational facilities and secretarial support (Flemmish speaking). Your work has been of great interest to me and I'm sure we can have many fruitful discussions. Please let me know at your earliest convience whether you are able to accept our invitation. It goes without saying we shall make housing arrangements for you.

Best regards.

Sincerely yours,

Gene Golub

Gene H. Golub



25 Years of SVD Applications

The Early Years

SVD **A**lgorithms

SVD **A**rchitectures (‘systolic arrays’)

SVD **A**pplications in…

- Biomedicine
- Speech and Audio
- Communications
- Radar
- Image Processing
- Control
- …

Lots of theory, few true realizations









25 Years of SVD Applications

SVD Comes of Age

Example: SVD in Digital Communications

A basic transmission principle is as follows:

- If matrix H represents a ‘MIMO’ channel
- Compute SVD: H=U.S.V’
- Use V as a precoder (at transmitter)
- Use U’ as an equalizer (at receiver)
- ‘Virtual channel’ is S (diagnal/decoupled) over which power resources are easily allocated (waterfilling)



25 Years of SVD Applications

SVD Comes of Age

Example: SVD in Digital Communications

In ADSL/VDSL

- 'SISO' channel H(z) is converted into matrix H through block transmission
- H is circulant matrix channel (cyclic prefix insertion)
- Hence: H=(IDFT).S.(DFT)

- $ADSL_{(1995)}$: 512-pt FFTs @4kHz: 20 Mops/sec
- $VDSL_{(2001/2006)}$: 4096-pt FFTs @4kHz: 200 Mops/sec



25 Years of SVD Applications

SVD Comes of Age

Example: SVD in Digital Communications

In ADSL

- Channel H(z) has impulse response longer than cyclic prefix length (hence previous slide does not work)
- Need 'channel shortening':

  H(z)*[unknown shortening filter]=[unknown short channel]
- With norm-constraint on filters, leads to TLS/SVD problem & solution
- Power iterations based realization (Alcatel-Lucent [2])

"Our science is pervasive but hidden.." J. Vandewalle, 2013

[2] T.Pollet et al., "Equalization for DMT based broadband modems", IEEE Communications Magazine 38(5), 2000

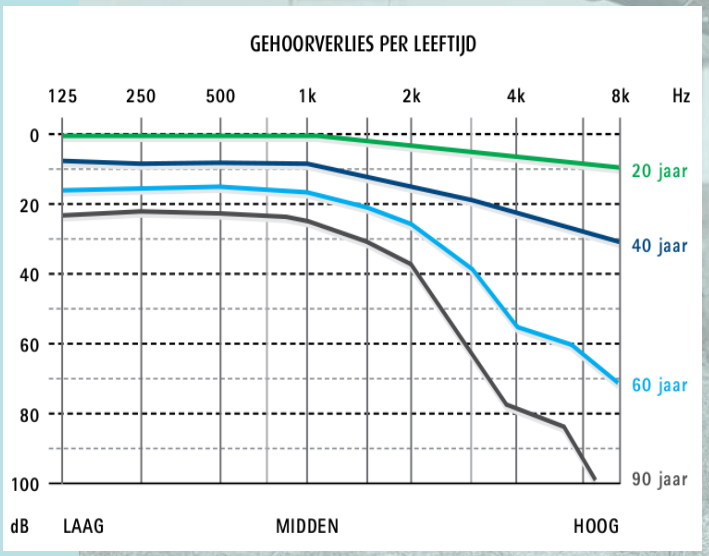


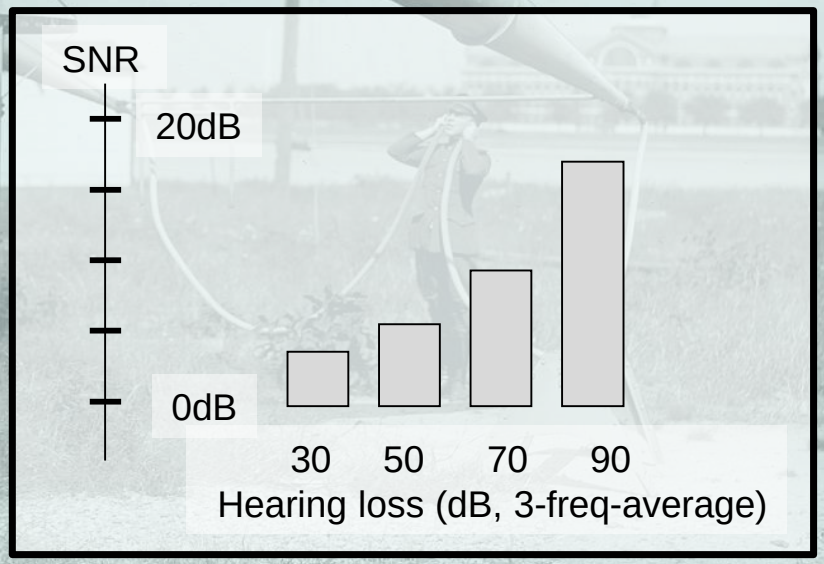
25 Years of SVD Applications

SVD Comes of Age

Example: SVD in Hearing Aids & Cochlear Implants

- Hearing impaired subjects need 5..10dB larger signal-to-noise ratio (SNR) for speech understanding in noisy environments







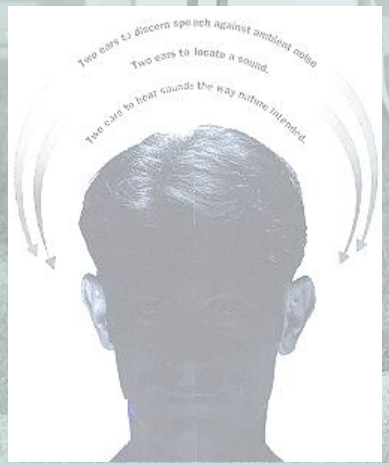
25 Years of SVD Applications

SVD Comes of Age

Example: SVD in Hearing Aids & Cochlear Implants

- Need noise reduction algorithm
- State-of-the-art: monaural 2-microphone noise reduction
- Near future: binaural noise reduction (2*2 microphones, imroved noise reduction and spatial hearing)
- Not-so-near future: multi-node noise reduction (see below)







25 Years of SVD Applications

SVD Comes of Age

Example: SVD in Hearing Aids & Cochlear Implants

- Beamforming based noise reduction (fixed/adaptive)
- (G)SVD based noise reduction:

  For each frequency bin i = 1..M (*)

  – Xi = speech+noise data matrix
  – Ni=noise data matrix
  – Compute GSVD(Xi,Ni)
  – Filtering is function of generalized singular vectors/values, tuning parameters, rank-estimates, etc

  Includes implicit low-rank approximation/correction of estimated speech autocorrelation matrix (Xi'.Xi-Ni'.Ni) [3]

(*) 256-pt FFTs @ 125Hz : 0,5 Mops/sec …☹

[3] R.Serizel et al., "Low-rank approximation based multichannel Wiener filter algorithms for noise reduction with applications in cochlear implants", internal report, to be submitted.



25 Years of SVD Applications
Current and Future SVDs

Example: SVD in Hearing Aids & Cochlear Implants

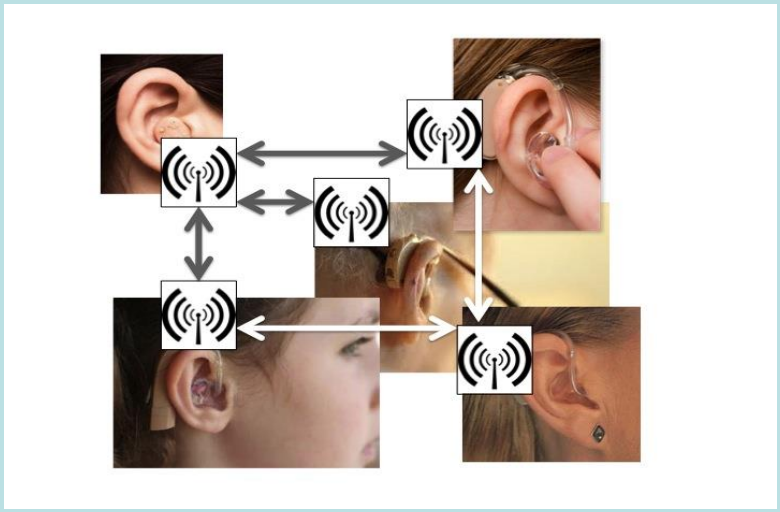
- (G)SVD based noise reduction lends itself well for generalization to binaural noise reduction [4]
  - Two hearing aids (L&R) with wireless link & cooperation
  - Opportunities:
    - More signals (e.g. 2*2 microphones)
    - Better sensor spacing (17cm i.o. 1cm)
  - Challenges:
    - Improved **localization** through 'cue preservation'
    - Improved **noise reduction** + benefit from 'binaural unmasking'
  - Constraints: power/bandwith/delay of wireless link
    - ..10kBit/s: coordinate program settings, parameters,…
    - ..300kBits/s: exchange 1 or more compressed (*) audio signals

[4] S.Doclo, et al., "Reduced-bandwidth and distributed MWF-based noise reduction algorithms for binaural hearing aids", IEEE Trans. ASL, 2009.



25 Years of SVD Applications
Current and Future SVDs

- Distributed SVD in Wireless (Acoustic) Sensor Networks





  - Multi-node noise reduction [5] , localization, …
  - Target is 10..100 nodes, 10 sensors/node
  - Challenge: With reduced communication, provide performance as if each node has access to all sensor signals in the network

[5] A.Bertrand et al., "Distributed adaptive node-specific signal estimation in fully connected sensor networks Part I: sequential node updating", IEEE Trans Signal Processing, 2010



25 Years of SVD Applications
Current and Future SVDs

- Multi-Linear Algebra / Tensor SVD

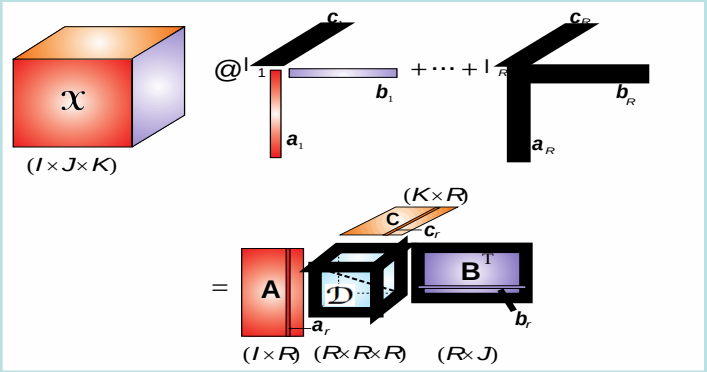


Figure 2: Dyadic and polyadic decomposition, where the latter may also be expressed in Tucker format with a diagonal core. The uniqueness properties of these decompositions are essential in blind source separation and latent variable analysis.

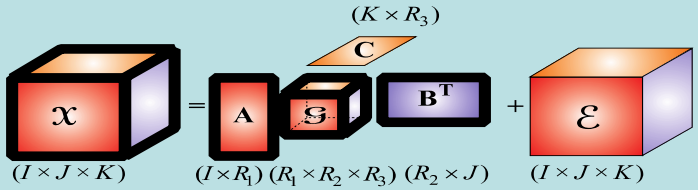


Figure 3: Tucker decomposition of a third-order tensor. The column spaces of **A**, **B**, **C** represent the signal subspaces for the three modes. The core tensor $\mathcal{G}$ is nondiagonal, accounting for possibly complex interactions among data components.





TU/e

erc



Conclusions



Now 25 years later…
Would the SVD prophecy not deserve
a Wikipedia page, too?

- For sure, time flies!
- In 25 years, Moore's law has provided 1k..10k-fold increase in compute power (Mops/sec -> Gops/sec)
- But: mobility/power, sampling rates, number of sensors…
- Some SVD applications have come alive, some of the SVD applications mountain yet to be realized
- Have to keep going…