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Distributed signal processing for WBANs and high-density biosensor networks

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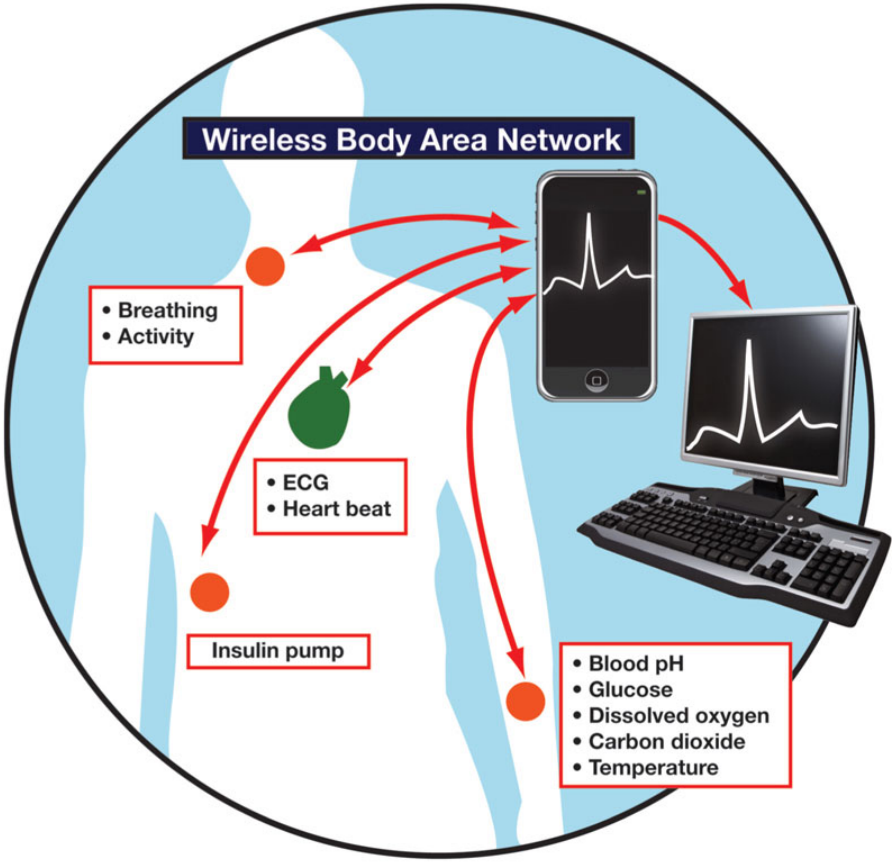
CATRENE Scientific workshop (Feb. 4, 2014)

Outline

1. Wireless body area networks
2. Distributed signal processing
3. Examples
4. Use case: eye blink artifact removal in wireless EEG sensor networks

Wireless body area networks (WBANs)

WBANS allow for continuous monitoring of, e.g.,



- Heart rate
- Temperature
- Blood pressure
- Gait
- Blood oxygen level
- Sweat
- …

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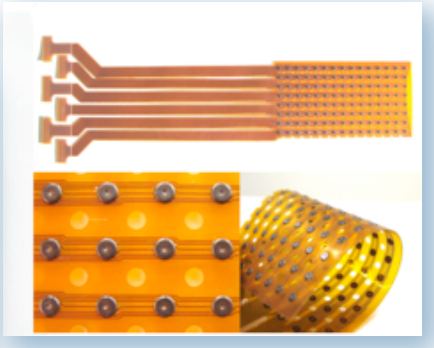
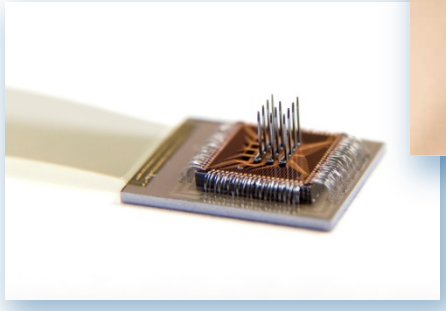
Wireless body area networks (WBANs)

But what about **data-intensive, high-density** systems ?

- High-density EEG ? (64-128 channels, Fs>200 Hz)
- High-density (s)EMG ? (>100 channels, Fs>2 kHz)
- ECoG, Neuroprobes? (10-100 channels, Fs>10 kHz)
- Binaural cochlear implants ? (2x 2-3 mics, Fs>20kHz)
- …





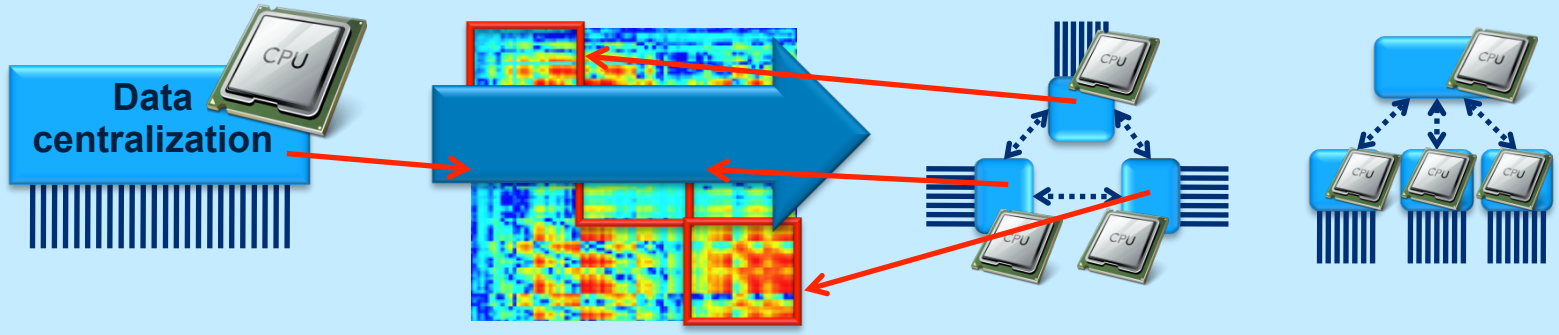
The ‘Data deluge’

- Many sensors/channels but…
  - insufficient **bandwidth** …
  - insufficient **computing power/memory** in CPU…
  - insufficient **time** …

… to transfer/process sensor data in **real-time**

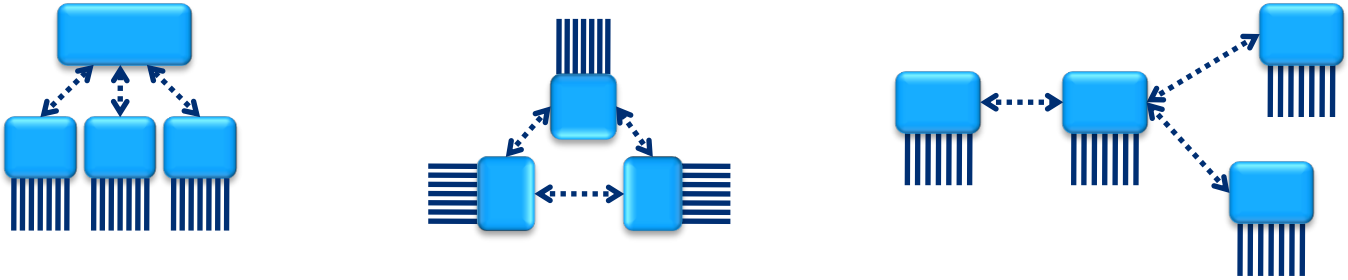
- Still want to exploit **all available information**

Avoid data centralization, shift DSP to the sensing nodes



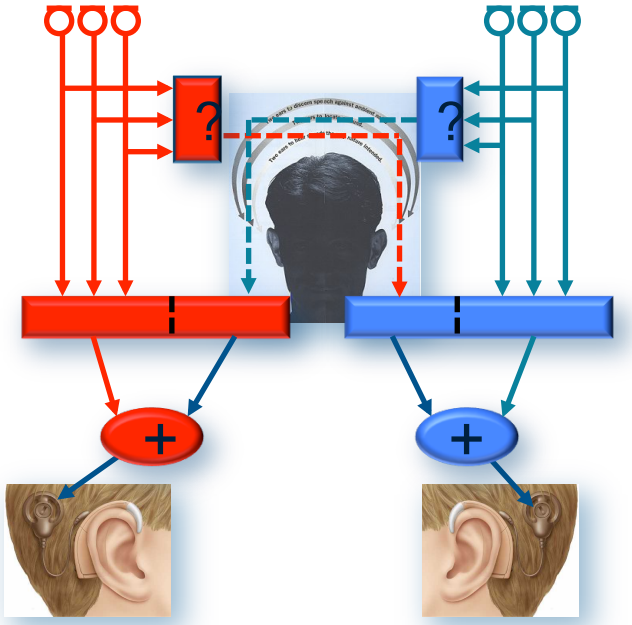
Distributed signal processing algorithms

- **Different topologies**



- **Distributed multi-channel** algorithms :
  - Principal Component Analysis (PCA)
  - Spatial filtering/beamforming
  - Multi-channel linear prediction (MLP)
  - Canonical Correlation Analysis (CCA)
  - Common Spatial Pattern (CSP) analysis
  - …

Future vision: binaural cochlear implants and wireless acoustic sensor networks (WASNs)



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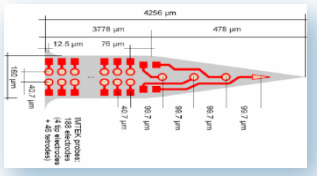
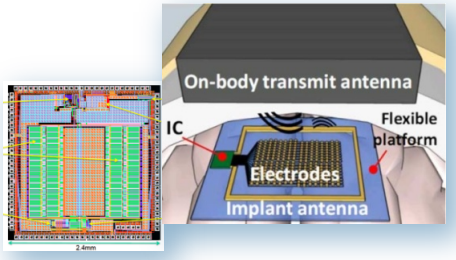
Future vision: modular neuro-implants

Trends:

- **Increasing electrode densities** (sufficient bandwidth?)
- **Wireless** transmission through skull
- **Modular/hierarchical** wireless systems:

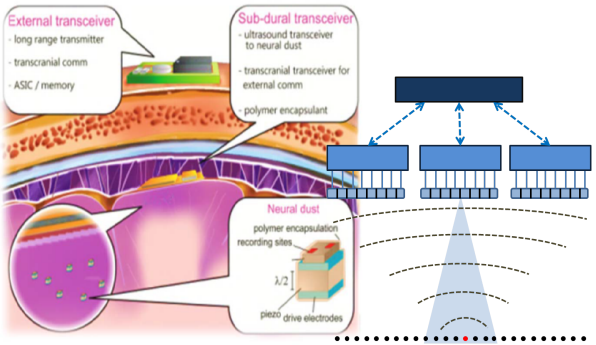


Wireless micro-ECoG node
1 module= 64 channels, 4mm



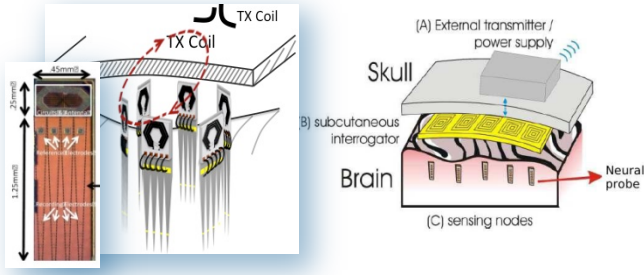
Maharbiz et al. (UC Berkeley, 2012)

"Neural dust"



Rabaey et al. (UC Berkeley, 2013)

Free-floating neuroprobes (wireless)



Biederman et al. (UC Berkeley, 2012)

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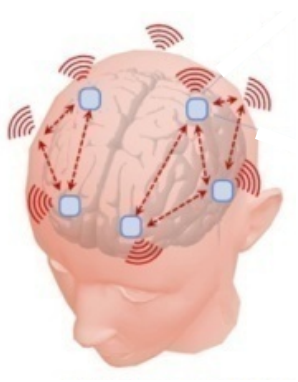
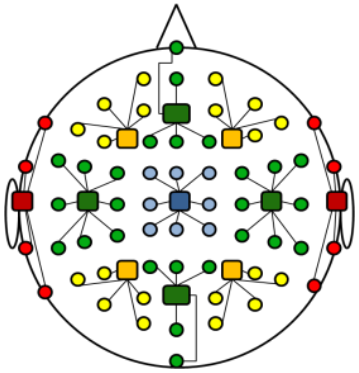
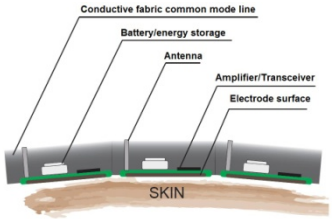
Future vision: wireless EEG sensor networks





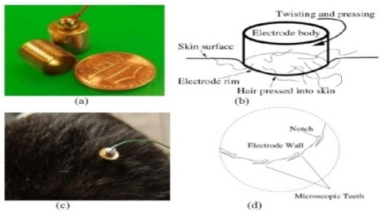
Modular systems with **wireless** EEG modules/nodes

(extreme miniaturization, flexible deployment, no ‘pulling’ of wires, …)



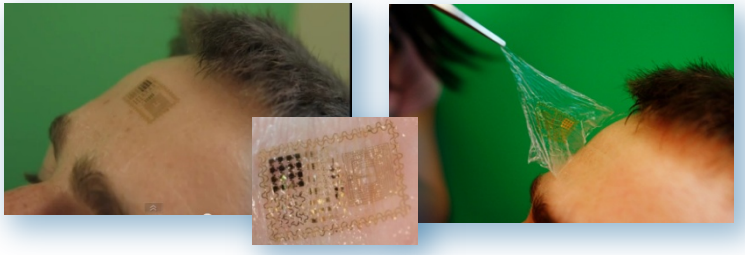
Wireless EEG sensor network (WESN)

Cauwenberghs et al.
(UC San Diego)



‘Skin-grabbing’ electrodes

Sclabassi et al.
(Univ. Pittsburgh)



Wireless EEG ‘e-skin’ patches

Rogers et al.
(Univ. Illionois)

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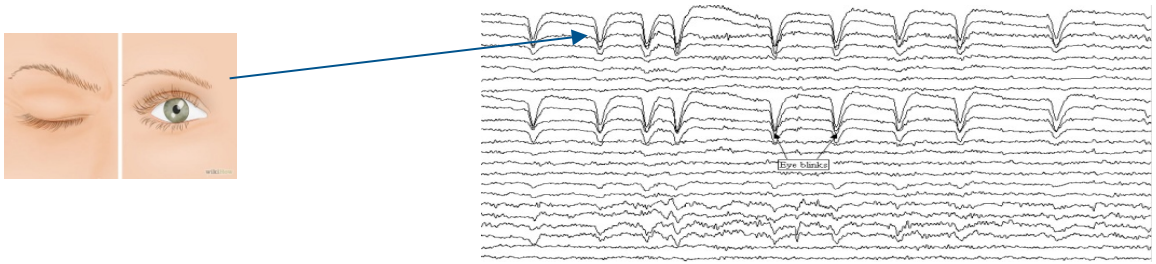
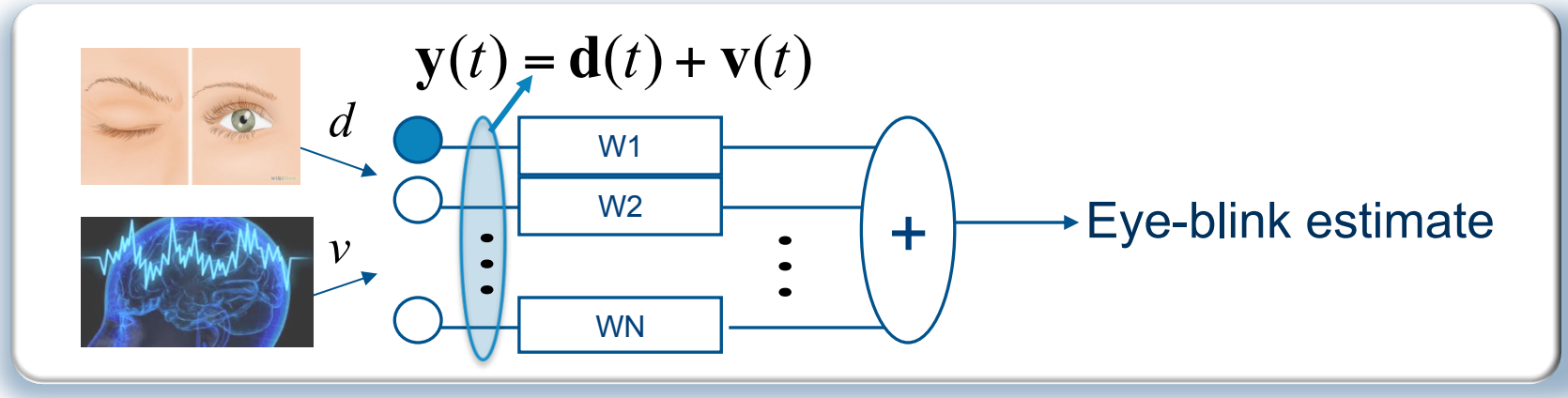
Case study: distributed eye-blink artifact removal in WESNs

- Eye-blink artifact hampers EEG signal analysis
- Usually removed with independent component analysis (ICA)
- Here: **Multi-channel Wiener filtering** (MWF)
  - Originally proposed for signal estimation in cochlear implants and hearing aids
  - Cheap (second-order statistics), time-recursive, …
  - Robust to noise

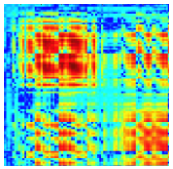


Multi-channel Wiener filter (MWF)

- Goal: estimate eye-blink artifact in each channel (and subtract)
- Compute optimal filter-and-sum operation in MMSE sense



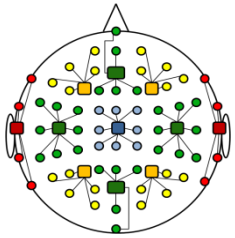
$$\mathbf{w} = (\mathbf{I} - \mathbf{R}_{yy}^{-1}\mathbf{R}_{vv})\mathbf{e}_{ref}$$

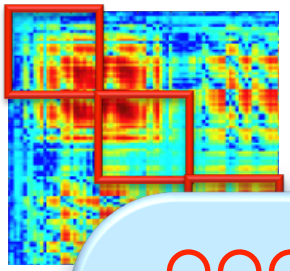


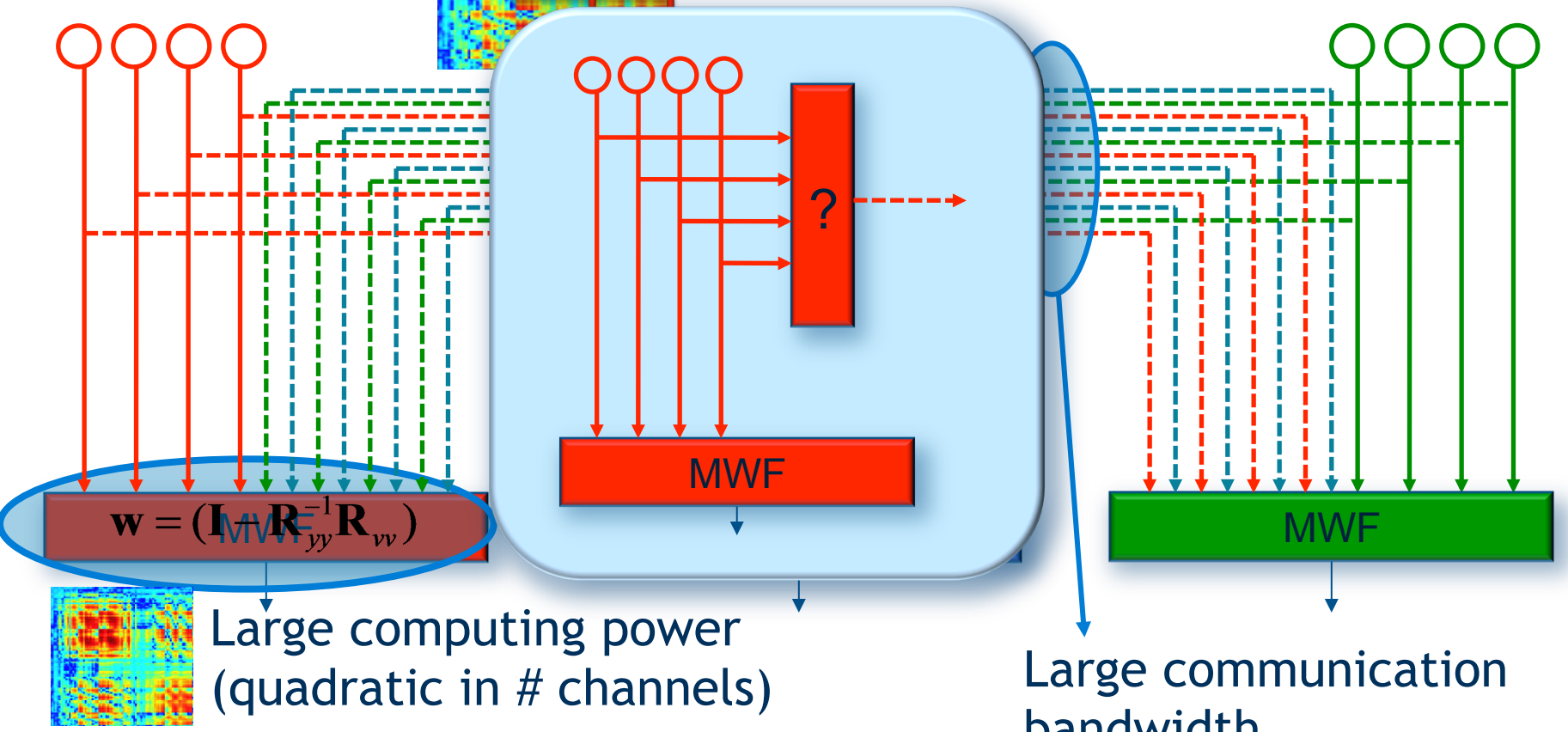
Artifact-free segments

Bertrand & Moonen , "Distributed eye blink artifact removal in a wireless EEG sensor network", IEEE ICASSP 2014

Wireless EEG sensor network



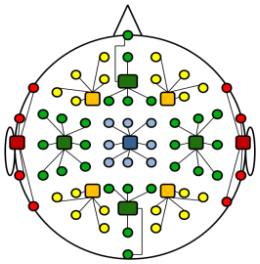


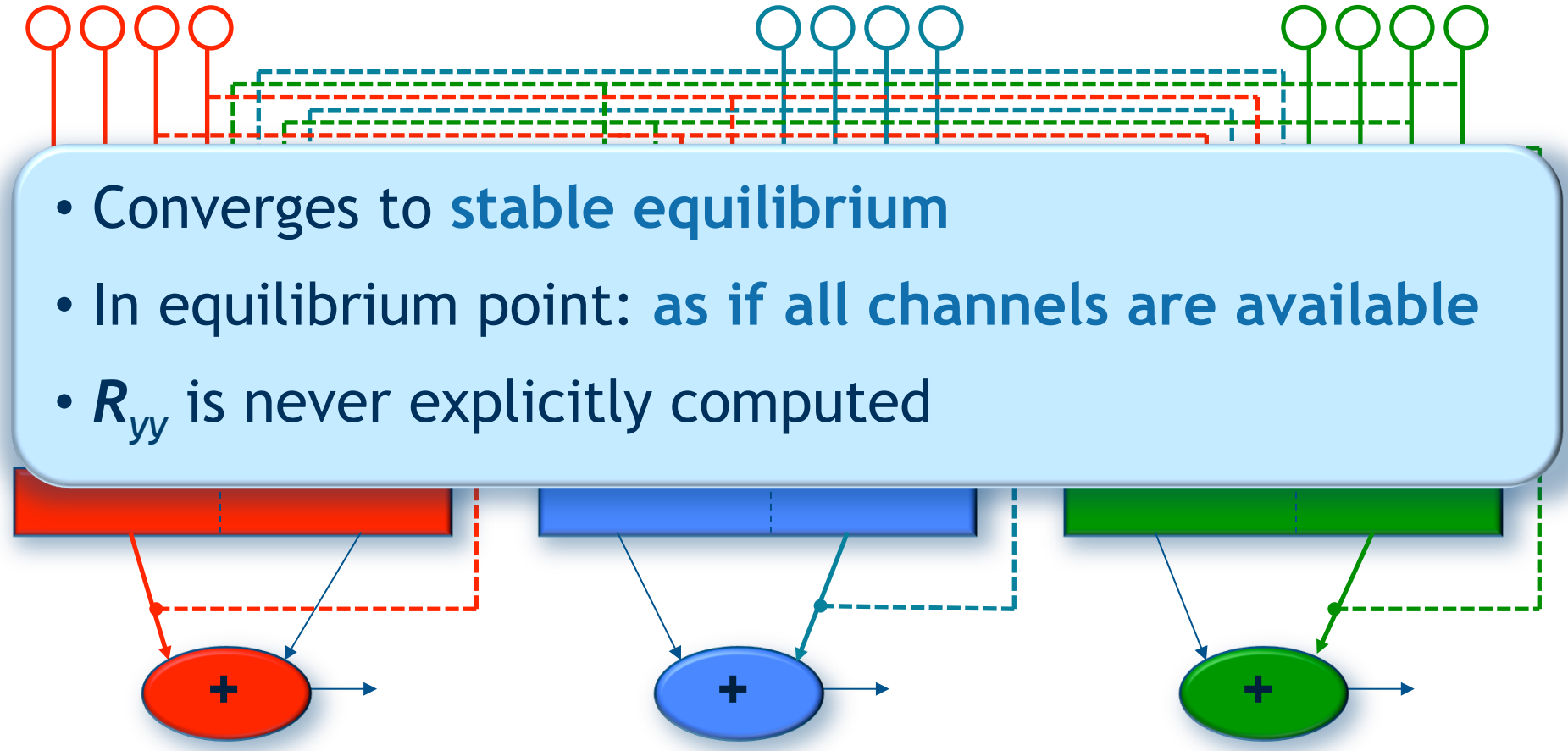


Large computing power
(quadratic in # channels)

Large communication
bandwidth

DANSE(*) algorithm

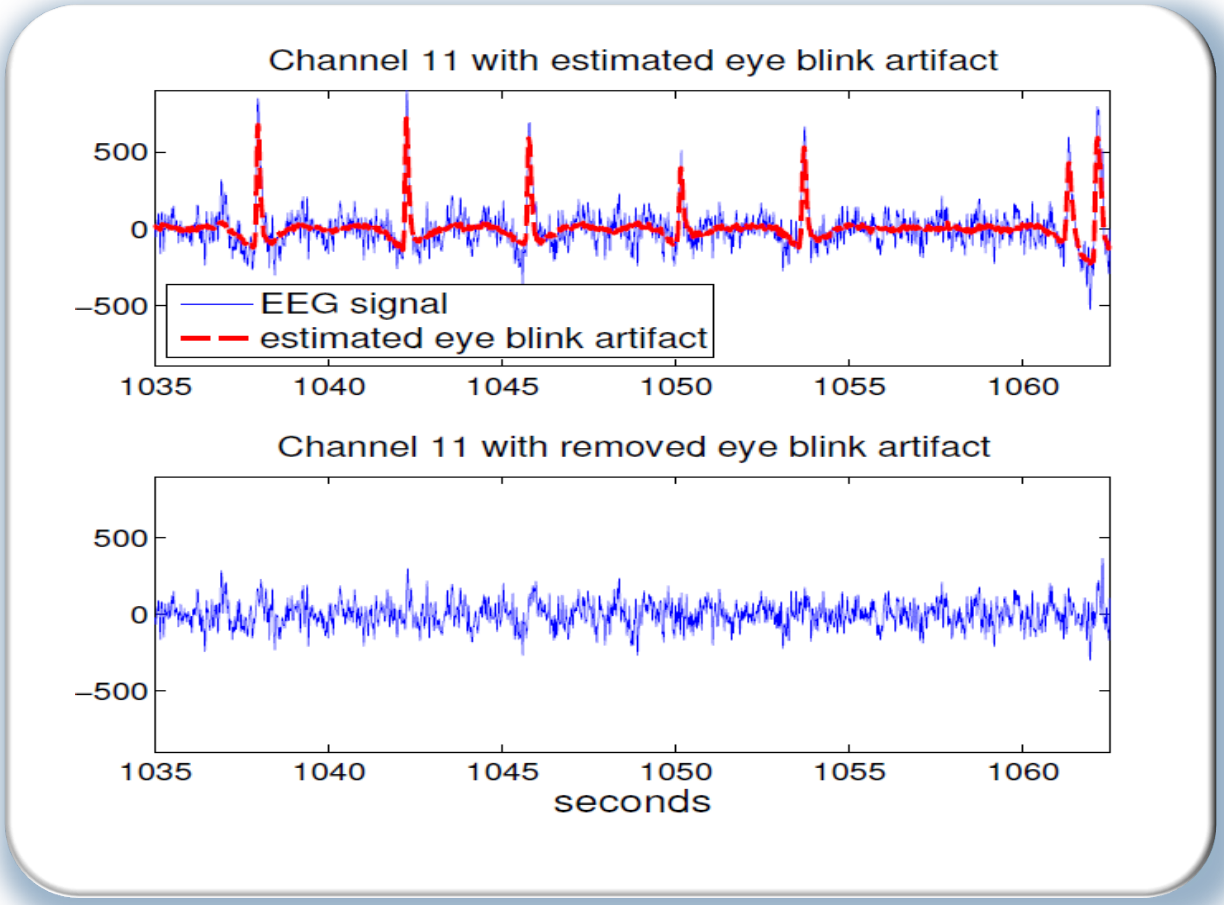




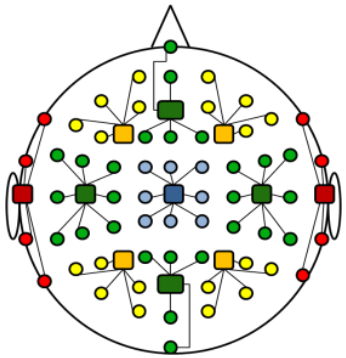
- Converges to **stable equilibrium**
- In equilibrium point: **as if all channels are available**
- $\boldsymbol{R}_{yy}$ is never explicitly computed

(*) DANSE=Distributed adaptive node-specific signal estimation
Bertrand & Moonen, *IEEE trans. on signal processing*, 2010

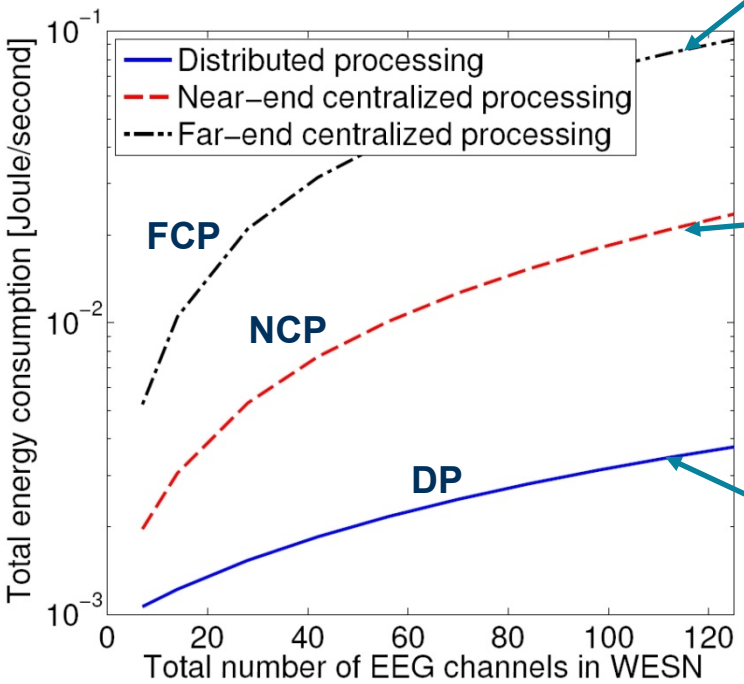
Distributed eye blink artifact estimation

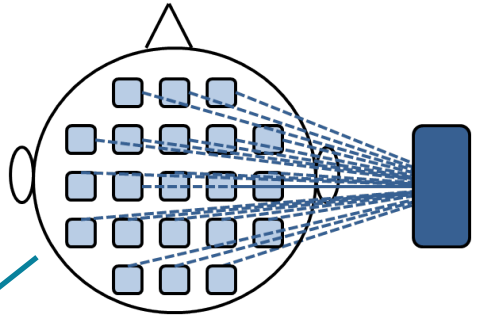


Processing alternatives in modular systems

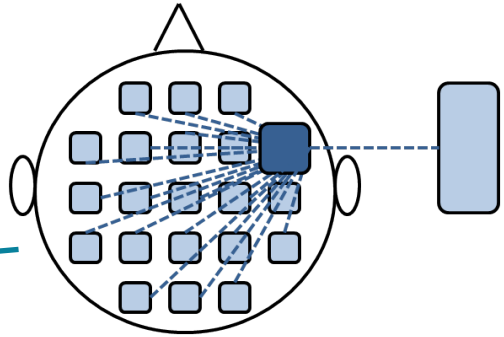


Hierarchical WESN

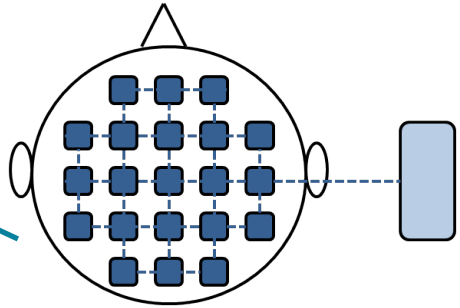




Far-end Centralized Processing



Near-end Centralized Processing



Distributed Processing

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Thank you

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