

# Neuromorphic Computing

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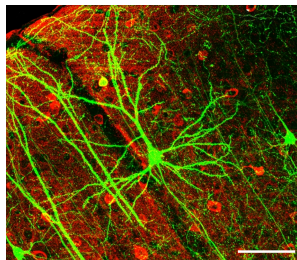
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# Motivation

## Wiederholung

Das menschliche Gehirn:

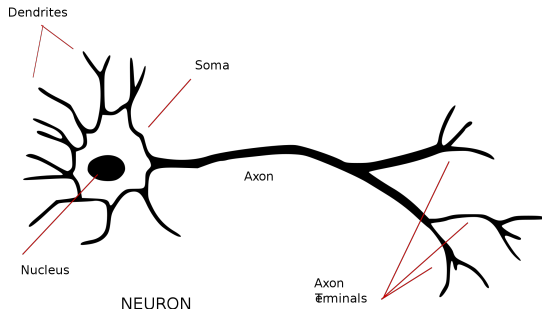
- ▶  $10^{11}$  Neuronen
- ▶  $10^{15}$  Synapsen
- ▶ Energieverbrauch: 20 W
- ▶ Zeitbereich ms





# Motivation

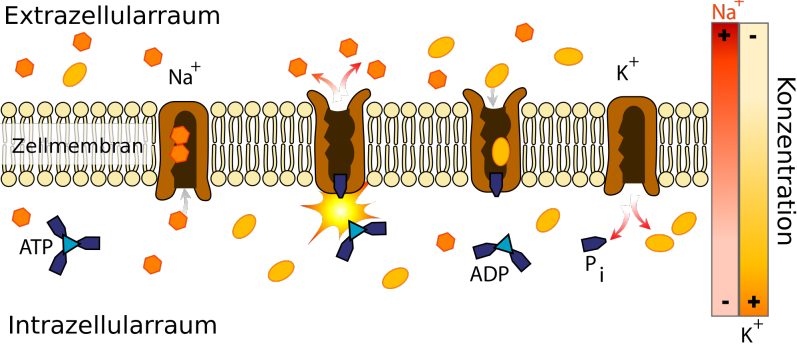
## Das Neuron



- ▶ Neuron = Nervenzelle
- ▶ Signalweiterleitung mittels elektrischer Impulse
- ▶ Dendriten nehmen Impulse auf und leiten sie durch das Axon weiter

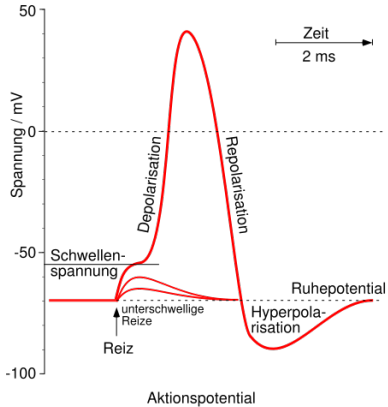
# Motivation

## Das Neuron

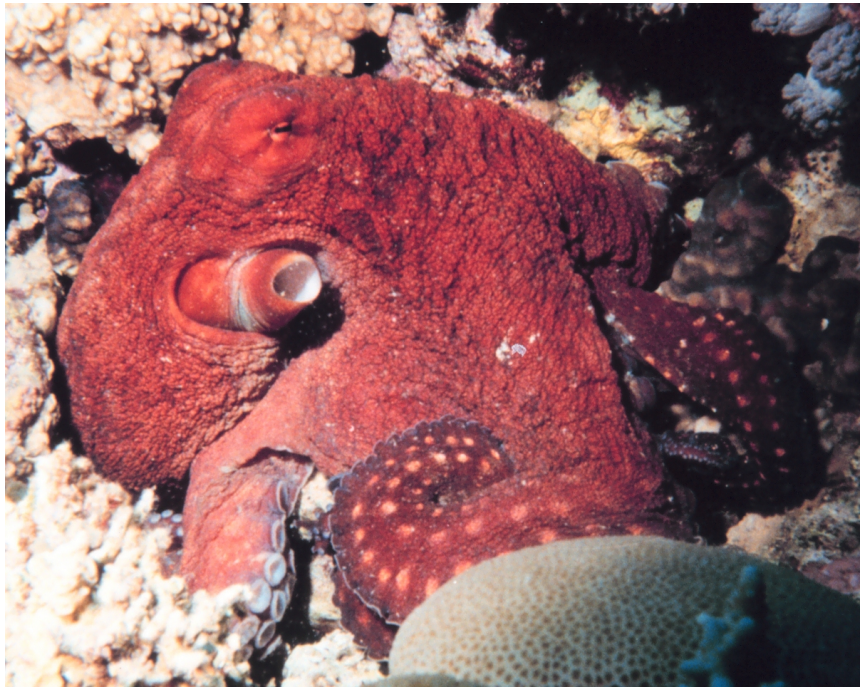


# Motivation

## Das Neuron



- ▶ Natriumkanäle öffnen sich.
- ▶ Kaliumkanäle öffnen sich.
- ▶ Natriumkanäle schließen sich.
- ▶ Kaliumkanäle schließen sich.



# Motivation

## Hodgkin-Huxley-Modell

$$C_M \frac{dV}{dt} = g_{Na} m^3 h (V - V_{Na}) + g_K n^4 (V - V_K) + g_L (V - V_L) + I_a$$
$$\frac{dn}{dt} = 0.01 \frac{V + 10}{\exp \frac{V+10}{10} - 1} (1 - n) - 0.125 \exp \frac{V}{80} n$$
$$\frac{dm}{dt} = 0.1 \frac{V + 25}{\exp \frac{V+25}{10} - 1} (1 - m) - 4 \exp \frac{V}{18} m$$
$$\frac{dh}{dt} = 0.7 \exp \frac{V}{20} (1 - h) - \frac{1}{\exp \frac{V-30}{10} - 1} h$$

# Motivation

Abschätzung

$$10^{15} \cdot 10^1 \cdot 10^2 = 10^{18}$$

# Motivation

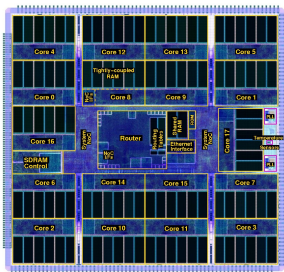
## Supercomputer

### Sunway TaihuLight

- ▶ 93 PetaFLOPS
- ▶ Kosten: 273.000.000 \$
- ▶ 15 MW
- ▶ etwa  $10^7$  Prozessorkerne

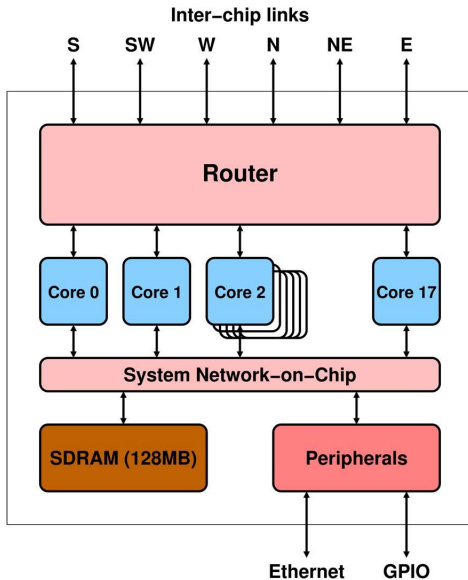
# SpiNNaker

- ▶ Universität Manchester
- ▶ Ziel 1.000.000 ARM968 Prozessoren
- ▶ 100 kW Energieverbrauch





# SpiNNaker



Exponential integrate and fire model (AdExp):

$$-C_m \frac{dV}{dt} = g_l(E - E_l) - g_l \exp \frac{V - V_{th}}{\Delta} - g_e(t)(V - E_e) + g_i(t)(V - E_i) + \omega(t)$$

# BrainScaleS

Sowjetischer Wassercomputer

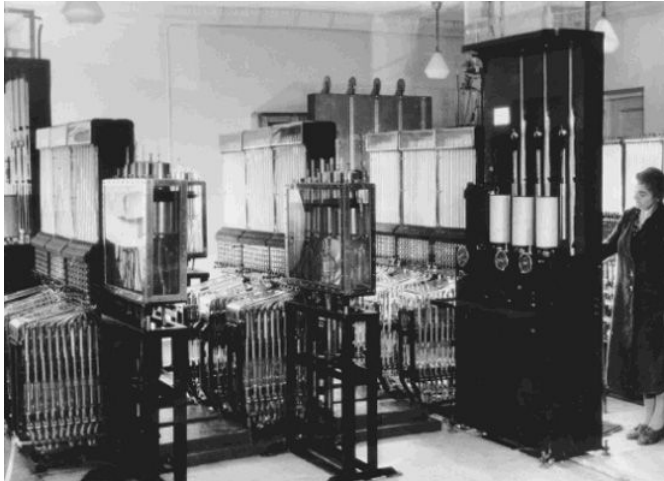


Abbildung:

[www.digitaljournal.com/img/7/7/5/0/6/8/i/1/3/3/o/water\\_computer.jpg](http://www.digitaljournal.com/img/7/7/5/0/6/8/i/1/3/3/o/water_computer.jpg)

# BrainScaleS

## Schaltung

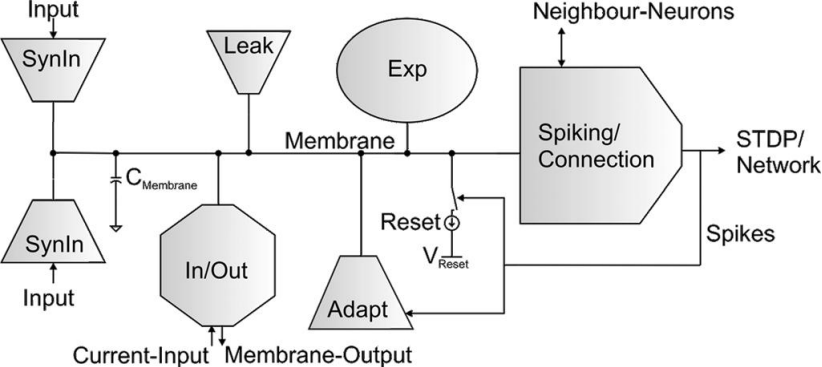
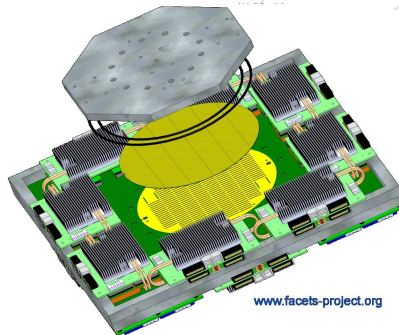


Abbildung: A Wafer-Scale Neuromorphic Hardware System for Large-Scale Neural Modeling, Figure 1

# BrainScaleS

- ▶ bis zu 10.000 mal schneller
- ▶ energieeffizient
- ▶ Nicht deterministisch



**Abbildung:** A Wafer-Scale Neuromorphic Hardware System for Large-Scale Neural Modeling, Figure 9

# BrainScaleS

## Neuroplastizität

- ▶ HICANN-DLS
- ▶ NUX
- ▶ Abbildung von Neuroplastizität am Neuron selbst
- ▶ Steuerung von außen möglich

TrueNorth

▶ IBM

# TrueNorth

- ▶ IBM
- ▶ Löser in Hardware programmiert



# TrueNorth

- ▶ IBM
- ▶ Löser in Hardware programmiert
- ▶ kommerzielle Anwendung

# Ausblick

- ▶ vorerst keine Revolution

# Ausblick

- ▶ vorerst keine Revolution
- ▶ wertvolles Werkzeug der Neurowissenschaften

# Ausblick

- ▶ vorerst keine Revolution
- ▶ wertvolles Werkzeug der Neurowissenschaften
- ▶ Energieeffizienz

# Quellen

- ▶ The SpiNNaker Project, Proceedings of the IEEE Vol. 102, No. 5, May 2014
- ▶ A Wafer-Scale Neuromorphic Hardware System for Large-Scale Neural Modeling
- ▶ A million spiking-neuron integrated circuit with a scalable communication network and interface (Science: Vol 345, Issue 6197 08 August 2014 )