Analog artificial neural network

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Digital (classic) vs. Analog

- software
- algorithm
- flexible structure
- von Neuman bottleneck
- processor clock

- hardware
- electric circuit
- technology
- faster
- low-power
- noise and inaccuracies
- defined structure
History

~1985 - 256 synapsys
~1995 - ~2017 - pause
~2014 - new start with memristor

Only forward propagation

1980  ~1995  ~2010  2018

FPGA  VLSI  Memristor
Today

- GPU
- Analog accelerator
  - forward propagation
    - as USB devices
    - mobile devices
- 2018 simulation of analog structure with supervised learning
Memristor

“memory-resistor”
All-memristive neuromorphic computing
ISAAC: CNN accelerator

- 128 x 128 crossbar arrays
- 450× speedup
- 150× lower energy than an NVIDIA K20M GPU
Learning

- Off-chip learning
- Chip-in-the-loop learning
- On-chip learning
Backpropagation (2018)

- circuit design
- SPICE
- memristive crossbar
- 180nm CMOS
Backpropagation

- not ideal components
- hard to simulation
My research

- on-chip design
- supervised learning
- all-analog

\( u_{in1} \rightarrow u_{in2} \rightarrow u_{out} \)

\( i_{in1} \rightarrow i_{out} \rightarrow u_{out} \)

\( u_{in} \rightarrow u_{out} \)

\( u_{w1} \rightarrow u_{in1} \rightarrow u_{w2} \rightarrow u_{in2} \rightarrow \ldots \rightarrow i_{net} \rightarrow u_{out} \)

subtractor  multiplier  activation f.  derivation of activation f.
Backpropagation in perceptron

\[ u_{w_{t+1}} = u_{w_t} - \eta \frac{\partial E_{\text{total}}}{\partial u_{w_t}} \]

\[ \frac{\partial E_{\text{total}}}{\partial u_w} = \frac{\partial E_{\text{total}}}{\partial u_{\text{out}}} \frac{\partial u_{\text{out}}}{\partial u_{\text{net}}} \frac{\partial u_{\text{net}}}{\partial u_w} \]

\[ \frac{\partial E_{\text{total}}}{\partial u_w} = (u_{\text{out}} - u_{\text{teacher}}) \frac{\partial u_{\text{out}}}{\partial u_{\text{net}}} u_{\text{in}} \]
Backpropagation between layers

\[
\frac{\partial E_{\text{total}}}{\partial u_w} = \frac{\partial E_{\text{total}}}{\partial u_{\text{out}}} \frac{\partial u_{\text{out}}}{\partial u_{\text{net}}} \frac{\partial u_{\text{net}}}{\partial u_w}
\]

\[
\frac{\partial E_{\text{total}}}{\partial u_{\text{out}}} = \sum_n \frac{\partial E_{\text{total}}}{\partial u_{\text{out}_n}} \frac{\partial u_{\text{out}_n}}{\partial u_{\text{net}_n}} \frac{\partial u_{\text{net}_n}}{\partial u_{\text{out}}}
\]

\[
\frac{\partial u_{\text{net}_n}}{\partial u_{\text{out}}} = u_{w_n}
\]
Simulation results

- SPICE

<table>
<thead>
<tr>
<th>$u_{in1}$ [V]</th>
<th>$u_{in2}$ [V]</th>
<th>$u_{target}$ [V]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.9</td>
<td>0.2</td>
</tr>
<tr>
<td>0.7</td>
<td>0.3</td>
<td>0.8</td>
</tr>
</tbody>
</table>
References


Thank you for your attention

Filip Paulů