Last Lecture: Debrief

Feedback dashboard

Quality:
- much worse
- worse
- average
- better
- much better

Relative frequency

Speed:
- way too slow
- too slow
- just right
- too fast
- much too fast

Relative frequency

Difficulty:
- much too easy
- slightly too easy
- just right
- slightly too difficult
- much too difficult

Relative frequency
Last Lecture: Debrief

Detailed Feedback

Things you did not like:
- this lecture should have come earlier

Things you did not understand:
- from LU to Cholesky
- complexity of various solves

Things you enjoyed:
- scipy.linalg references
- LAPACK intro
- behind-the-scenes of scipy.linalg.solve
- different types of matrices and their properties
- blackboard
- history
<table>
<thead>
<tr>
<th></th>
<th>0 Introduction</th>
<th>Learning is Computation, Computation is Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 Mathematical Background</td>
<td>Gaussian and Least-Squares Inference</td>
</tr>
<tr>
<td></td>
<td>2 Integration — Quadrature</td>
<td>Integration is Regression</td>
</tr>
<tr>
<td></td>
<td>3 Integration — Bayesian Quadrature</td>
<td>Regression for Integration</td>
</tr>
<tr>
<td></td>
<td>4 Integration — Monte Carlo I</td>
<td>Randomness is a flawed concept</td>
</tr>
<tr>
<td></td>
<td>5 Integration — Monte Carlo II</td>
<td>Markov Chains to Explore and Exploit</td>
</tr>
<tr>
<td></td>
<td>6 Integration — Monte Carlo III</td>
<td>Efficient Markov Chains</td>
</tr>
<tr>
<td></td>
<td>7 Linear Algebra — Direct Methods</td>
<td>Solving Linear Systems by Bookkeeping</td>
</tr>
<tr>
<td></td>
<td>8 Special Lecture</td>
<td>The Climate Impact of Computing and AI</td>
</tr>
<tr>
<td></td>
<td>9 Linear Algebra — Iterative Methods</td>
<td>Solving Linear Systems as Optimization</td>
</tr>
<tr>
<td></td>
<td>10 Optimization — Basic Methods</td>
<td>Minimizing Smooth Multivariate Functions</td>
</tr>
<tr>
<td></td>
<td>11 Optimization — Quasi-Newton</td>
<td>Curvature can be Learnt</td>
</tr>
<tr>
<td></td>
<td>12 Bayesian Optimization</td>
<td>Optimization of Empirical Functions</td>
</tr>
<tr>
<td></td>
<td>13 Revision</td>
<td></td>
</tr>
</tbody>
</table>
Why this Lecture?

https://lecturesforfuture.org

Data: Mauna Loa Observatory, National Oceanic and Atmospheric Administration, 26 September 2018

ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_weekly_mlo.txt
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This Is Unprecedented
Global warming relative to 1850-1900 (°C)

- **Observed monthly global mean surface temperature**
- **Estimated anthropogenic warming to date and likely range**

**Likely range of modeled responses to stylized pathways**
- Global CO₂ emissions reach **net zero in 2055** while net non-CO₂ radiative forcing is **reduced after 2030** (grey in b, c & d)
- Faster CO₂ reductions (blue in b & c) result in a **higher probability** of limiting warming to 1.5°C
- No reduction of net non-CO₂ radiative forcing (purple in d) results in a **lower probability** of limiting warming to 1.5°C

Source: IPCC 2018, Summary for Policymakers,

Action must be Ubiquitous and Universal

Source: IPCC 2018, Summary for Policymakers,


b) Stylized net global CO₂ emission pathways
Billion tonnes CO₂ per year (GtCO₂/yr)

- CO₂ emissions decline from 2020 to reach net zero in 2055 or 2040

Faster immediate CO₂ emission reductions limit cumulative CO₂ emissions shown in panel (c).

c) Cumulative net CO₂ emissions
Billion tonnes CO₂ (GtCO₂)

- Maximum temperature rise is determined by cumulative net CO₂ emissions and net non-CO₂ radiative forcing due to methane, nitrous oxide, aerosols and other anthropogenic forcing agents.

d) Non-CO₂ radiative forcing pathways
Watts per square metre (W/m²)

- Non-CO₂ radiative forcing reduced after 2030 or not reduced after 2030
Action must be Ubiquitous and Universal

Source: IPCC 2018, Summary for Policymakers,

as well as substantial risks and institutional and social constraints to deployment related to governance, ethics, and impacts on sustainable development. They also do not mitigate ocean acidification. (medium confidence) {4.3.8, Cross-Chapter Box 10 in Chapter 4}

Non-CO₂ emissions relative to 2010
Emissions of non-CO₂ forcers are also reduced or limited in pathways limiting global warming to 1.5°C with no or limited overshoot, but they do not reach zero globally.

Global total net CO₂ emissions
Billion tonnes of CO₂/yr

In pathways limiting global warming to 1.5°C with no or limited overshoot as well as in pathways with a higher overshoot, CO₂ emissions are reduced to net zero globally around 2050.

Four illustrative model pathways

Timing of net zero CO₂
Line widths depict the 5-95th percentile and the 25-75th percentile of scenarios

Pathways limiting global warming to 1.5°C with no or limited overshoot
Pathways with higher overshoot
Pathways limiting global warming below 2°C (Not shown above)
Action must be Ubiquitous and Universal

Source: IPCC 2018, Summary for Policymakers,

Summary for Policymakers

Changes in energy demand are associated with improvements in energy efficiency and behaviour change.

P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.
Today:

1. Where is this CO$_2$ coming from?
2. How much of it is caused by computing, and where?
3. What can we do to reduce the CO$_2$ emissions caused by computing and AI?
4. What can AI & ML do to mitigate the climate crisis?
What is the status quo?

Annual CO₂ production per person in Germany

source: Umweltbundesamt — https://uba.co2-rechner.de/

- public expenditure includes infrastructure (incl. waste and water), education, social services, defense.
- 4.56 kWh for stuff ≈ 370 €/month (but averaged over household)
- stuff is essentially CO₂ produced by others during their work time
- 0.76t CO₂ electricity = 1450 kWh/a = 166W
- Current electricity mix in Germany: ~ 500 g CO₂ / kWh
- heating assumes a mix of energy sources. Specific heat of water 0.00117 kWh/l/°C. Showering at 40°C · 9 l/min = 0.3 kWh/min ≈ 10 kg CO₂/h
- mobility: for intercontinental flights: 0.24t CO₂ / h
What is the status quo?

Annual CO\textsubscript{2} production per person in Germany

source: Umweltbundesamt — https://uba.co2-rechner.de/

- food: for the average German, 1.74 t/a. Changing habits would cause changes to
  - vegetarian: 1.29 t/a (26\% reduction)
  - vegan: 1.04 t/a (40\% reduction)
  - mixed food, but organic/regional/seasonal: 1.45 t/a (17\% reduction)

- IPCC goal: zero net emissions by 2050. “Net emissions are defined as anthropogenic emissions reduced by anthropogenic removals.”

- On the individual level, this might translate to about 3 t/a. Some this can and must be achieved by political and societal changes and regulation. But, voluntary or not, lifestyles \textbf{will} change.
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## Some Misconceptions

before we even get to the numbers

| Computing just needs electricity, which can be produced sustainably. |
| In the *near* future, virtually *everything* will have to run essentially on electricity. Reduction of existing electricity usage is just as crucial as transition of currently non-electric power consumption. |

| “Professional” CO₂ production doesn’t count |
| The CO₂ produced in a professional setting effectively form the customers’ CO₂ footprint under “stuff”. |

| Corporations are responsible for the majority of emissions. |
| There is a meaningful debate to be had about most effective regulation (carbon tax). But in the end, CO₂ is produced by humans. The required changes will affect our lifestyles, drastically. |

| Google runs very efficient data centers |
| It’s great when technology companies invest in clean electricity. If they needed *less* energy, those ressources could still be used elsewhere, though. |
At home:
- 30” LED screen: 50W
- 65” LED TV (Samsung LS03): 143W
- Mac mini: 6W (inactive) - 85W (max)
- intel Core i7 CPU ~ 100W (thermal design power)
- nvidia GeForce RTX 2080 Ti: 17W (idle) – 280W (max)
- o2 standard-issue wifi router: 10W
- Fridge/Freezer (Miele KF 37233 iD, A+++): 156 kWh/a = 18W

Mobile:
- Apple USB phone charger, no load: 0.012W.
- Apple iPhone X Battery capacity: 10,35 Wh (typical draw < 1W)

HPC:
- Tesla V100, NVlink: 300W (max)
- GPU hypervisor (8× Tesla V100, 36-core intel Xeon Skylake, 384 GB RAM, 2 SSD’s): ~ 3kW (max)
Thus

- forget about ‘unplugging your charger’. Actually, just forget about your phone’s energy use. Mobile devices are among the most efficient users of electricity out there.
- if you’re running a desktop computer as a home server all day (~ 60W = 525 kWh/a), that may be about 30% of your total electricity consumption and adds about 0.26t CO$_2$ to your annual footprint. That’s roughly the difference between a standard diet and one exclusively on local, organic, seasonal food. If you’ve got a monitor running on it continuously, double that.
- running your gaming PC at full load (600W, incl. 2 monitors) for 2h a day is similar to the above.
- your wifi router (10W) likely produces about 44kG of CO$_2$ per year, a similar amount to your fridge!
- if you’re training a deep network on imagenet (1 hypervisor, 1 week), that’s about 0.25 t CO$_2$, too.

Computing Devices at home are not the biggest source of your carbon footprint. But especially devices that are **plugged into mains and running for significant times of the day** have a non-negligible impact. Much of it can relatively easily be reduced with some discipline. Switch off your router when you’re not home!
embodied CO₂:

- Dell Latitude E6400 Laptop: 200kg CO₂ for manufacturing & transport (May 2010, assumes renewable electricity)
- iPhone 8 (report from September 2017): 56kg CO₂ for manufacturing and transport

Thus

- These numbers are probably too small, because they come from the producers. Nevertheless:
- if you’re buying a new laptop every 3 years, the embodied CO₂ might be about 20% of the total emissions associated with the device.
- embodied CO₂ is nontrivial, but likely smaller than that produced during use
Numbers in Context III: The Cloud
Consumer devices seem to use the bulk of electric energy for computing.

sources: Google, Deutsche Telekom, US Dept. of Energy

How much CO₂ does your Internet use generate?

- 2009: “a single [Google] search accounts for about 0.2g of carbon”
- 2017: Google uses about 2.6GW of energy for their operations (all renewable). Note: This includes youtube. (German electricity generation: ~28GW). Google makes about 3% of their revenue in Germany, so about 2.6 GW · 0.03/80 000 000 ≈ 1W for each German.
- Deutsche Telekom uses about 142kWh / TB in Germany.
- all US Datacentres jointly draw about 8GW of power (source: US Dept. of Energy), using 1,6% of all US electricity (the US produces 480GW electricity on average).

- if you’re using 10GB/month, that’s ~ 17kWh, i.e. 8.5kg CO₂ (kg!) per year for communication.
- If a third of your data comes from Google (youtube!), then producing that data in the cloud probably uses about 26kWh of energy (3W) — less than your wifi router!
- the main energy consumption on the internet is probably not communication but computation. Even that, though, probably amounts to only a few kG CO₂ per person and year.
Takeaways:

- your personal CO₂ footprint from computing likely stems primarily from
  - desktop computing
  - embodied CO₂ in devices
  and not so much from data and communication

- but if you are a professional in charge of significant computing power, then computing efficiency may be one of the most significant ways you can reduce CO₂ emission.

At Google Deepmind, each Developer has personal access to about 8 GPUs. If you’re in control of a 8×V100 hypervisor and keep it busy (3kW = 13.14 t CO₂ / a), then thinking hard about how you train your neural networks might be your biggest opportunity to reduce CO₂ emissions.
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In contrast to more established CS areas (like information retrieval, networks, compression, os), machine learning, data analysis and AI are resource inefficient, and the market is currently willing to allow such wastefulness. An individual developer can make a significant difference.
The typical Machine Learning PhD student flies to about one international conference per year.

- AISTATS 2019: Okinawa, Japan
- ICLR 2019: New Orleans, USA
- NeurIPS 2019: Vancouver, Canada
- ICML 2019: Long Beach, California, USA

A single intercontinental return flight FRA to LAX produces 5.73 t CO$_2$. That’s like running that hypervisor for 160 days! The biggest climate cost of a NeurIPS paper is not the computing, but flying in to present it.
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Contributing Our Special Skills


Tackling Climate Change with Machine Learning

David Rolnick¹*, Priya L. Donti², Lynn H. Kaack³, Kelly Kochanski⁴, Alexandre Lacoste⁵, Kris Sankaran⁶,⁷, Andrew Slavin Ross⁸, Nikola Milojevic-Dupont⁹,¹⁰, Natasha Jaques¹¹, Anna Waldman-Brown¹¹, Alexandra Luccioni⁶,⁷, Tegan Maharaj⁶,⁷, Evan D. Sherwin², S. Karthik Mukkavilli⁶,⁷, Konrad P. Kording¹, Carla Gomes¹², Andrew Y. Ng¹³, Demis Hassabis¹⁴, John C. Platt¹⁵, Felix Creutzig⁹,¹⁰, Jennifer Chayes¹⁶, Yoshua Bengio⁶,⁷

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Just a few Picks

many more ideas in the op.cit.

[9x236]https://arxiv.org/abs/1906.05433v1

- **Mitigation**, e.g.
  - generation and demand forecasting and control in smart grids
  - enabling control of nuclear fusion

- **Transportation** and **Smart Cities**, e.g.
  - freight routing and consolidation
  - improving shared and low-carbon options (bike sharing, electric scooters, public transport …)
  - smart buildings (automatic shading, heating, appliances)

- **Industry, Farming, Forestry**, e.g.
  - efficient supply chain management
  - lightweight construction
  - remote sensing of emissions
  - automated and smart afforestation and precision agriculture

- **Enabling Science, Society and Individuals**, e.g.
  - improving climate forecasting and biodiversity/ecosystem monitoring and modelling
  - societal modelling for food security, migration, crises, disaster relief
  - providig tools for individual and societal action
This paper was written by people who don’t know ML, and people who don’t know the science.

Some of the ideas are very aspirational, high-risk, long-term (and the authors say so).

ML cannot solve these problems alone. In most cases, it is a supporting tool for scientific, technological, and societal advances. Computer scientists need to listen.

The solutions have to be deployed, too. We don’t just need scientific advances, but people willing to turn climate relief into a business opportunity.
computing is a significant, but not the dominant consumer of energy
a large part of computing consumption happens at home, thus individual action matters
but CS professionals also have significant leverage to affect resource efficiency through careful software design
AI and ML have the potential to help enable technological and societal change to mitigate the climate crisis — in careful support of the corresponding core communities.

If you are passionate about a particular use of ML to mitigate climate change, feel invited to propose your own Masters thesis topic, apply for a PhD position, or startup seed funding!

Incidentally: There's an open PhD position in CO$_2$ soil-transport modeling available (with Thomas Scholten, soil science) in my lab!