Accelerated Bayesian inference of multimessenger astronomy with JAX and machine learning

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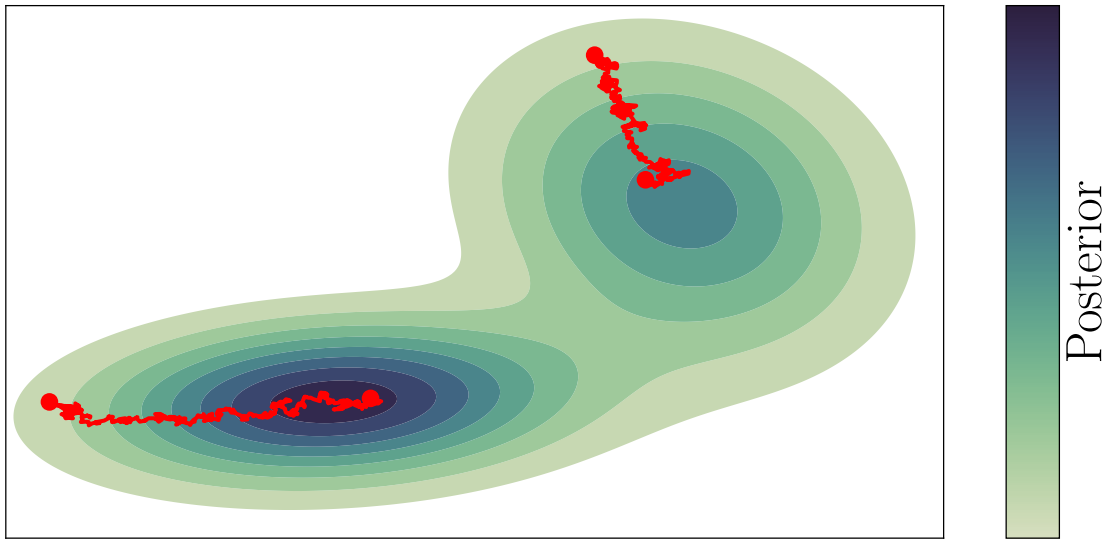
Bayesian inference

Bayesian inference: get posterior of parameters θ from data d

$$p(\theta|d) = \frac{p(d|\theta)p(\theta)}{p(d)}$$

Problem: Computationally expensive for multimessenger data + EOS



Nuclear Multi-Messenger Astrophysics

- NMMA: Nuclear Multi-Messenger Astrophysics (Peter T.H. Pang)

- A Pythonic library for probing nuclear physics and cosmology with multimessenger analysis
  - Gravitational waves, kilonovae, gamma-ray bursts

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- Used for overview of EOS constraints, with "precomputed" EOS set (arXiv:2402.04172)
  - Metamodel
  - Speed-of-sound extension scheme
  - 100 000 EOS

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Next step: Infer EOS parameters directly from multimessenger data, upgrade software for future detectors

JAX

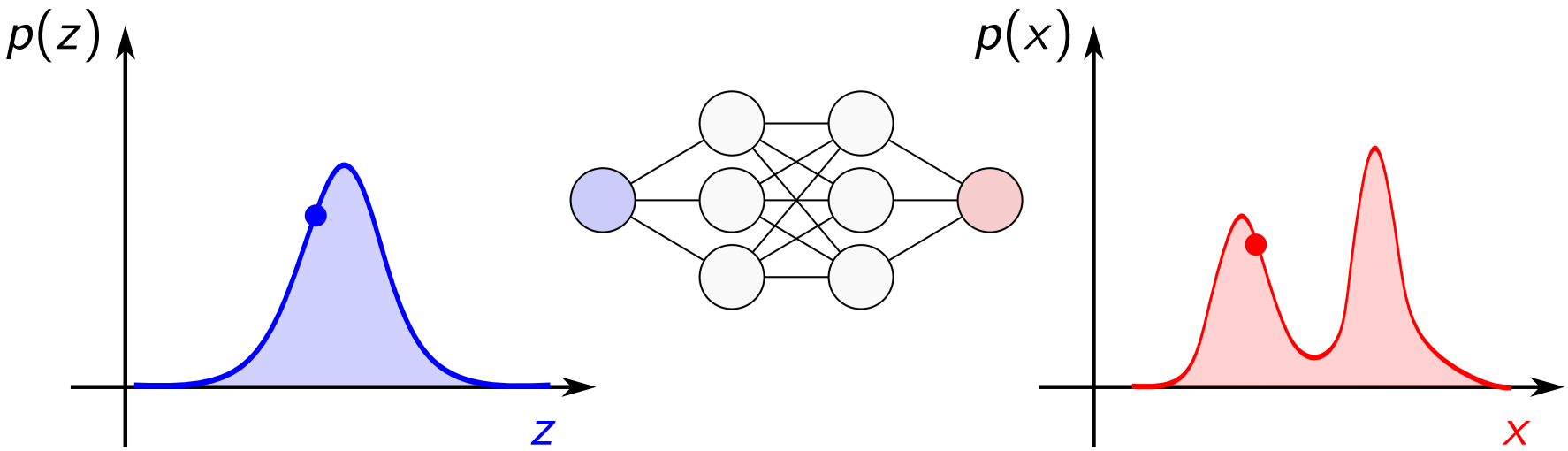
JAX = NUMPY + composable transformations:

1. Automatic differentiation
2. Just-in-time (JIT) compilation
3. GPU acceleration
4. Parallelization

Potential for accelerating science, without resorting to machine learning!

Normalizing flows

- Generative machine learning model
- Learn mapping between latent and parameter space
- Enable approximate sampling from complicated distributions



Accelerating Bayesian inference for MMA: progress

- Gravitational waves (arXiv:2404.11397)
  - Waveforms: $\mathcal{O}(10^3)$ faster
  - Analyze binary neutron stars in 15 – 30 minutes rather than $\mathcal{O}(\mathrm{hours})$

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- Future work:
  - Next-generation gravitational wave detectors
  - Combine into one multimessenger analysis pipeline

Thanks for listening!

Our JAX ecosystem:

- Normalizing flow-enhanced MCMC sampler: `kazewong/flowMC`
- Gravitational waveforms: `tedwards2412/ripple`
- Gravitational waves inference toolkit: `kazewong/jim`
- EOS code and TOV solver: `tsunhopang/jose` (*work in progress*)
- Kilonovae and GRB: `ThibeauWouters/fiesta` (*work in progress*)