Multiparameter optimization of a magneto-optical trap using deep learning

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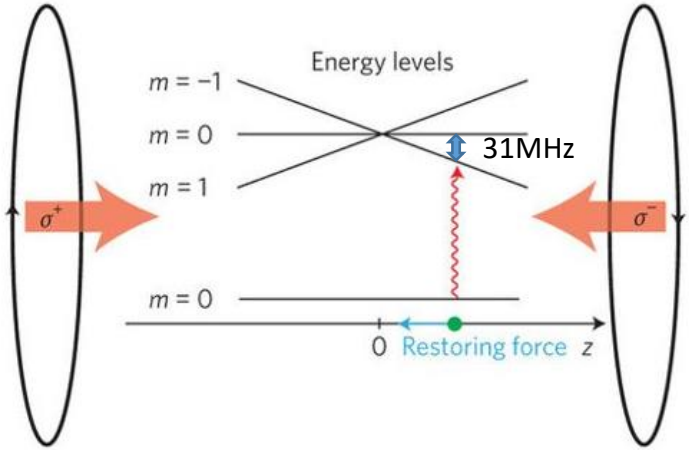
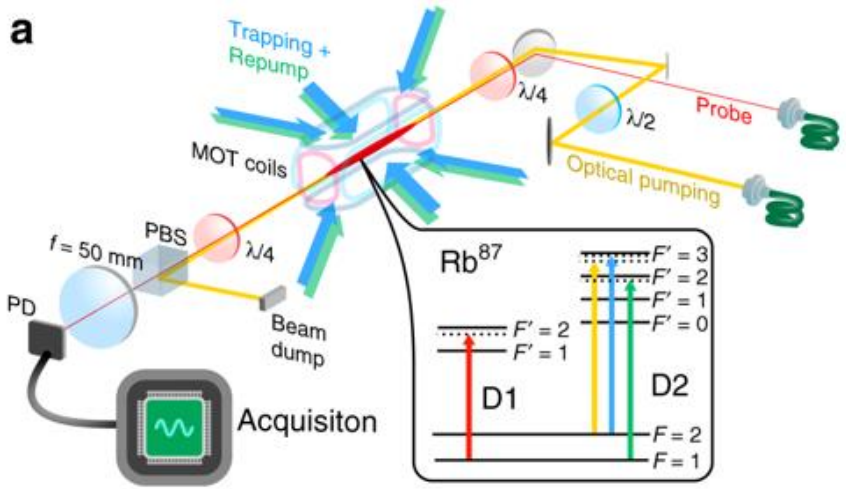
- Research Interest
  - Quantum memory
  - Atom detection
  - Squeezed light generation
  - Squeezing for gravitational wave sensing
- Recent Papers
  - Dynamical observations of self-stabilizing stationary light (2017)
  - Highly efficient optical quantum memory with long coherence time in cold atom (2016)

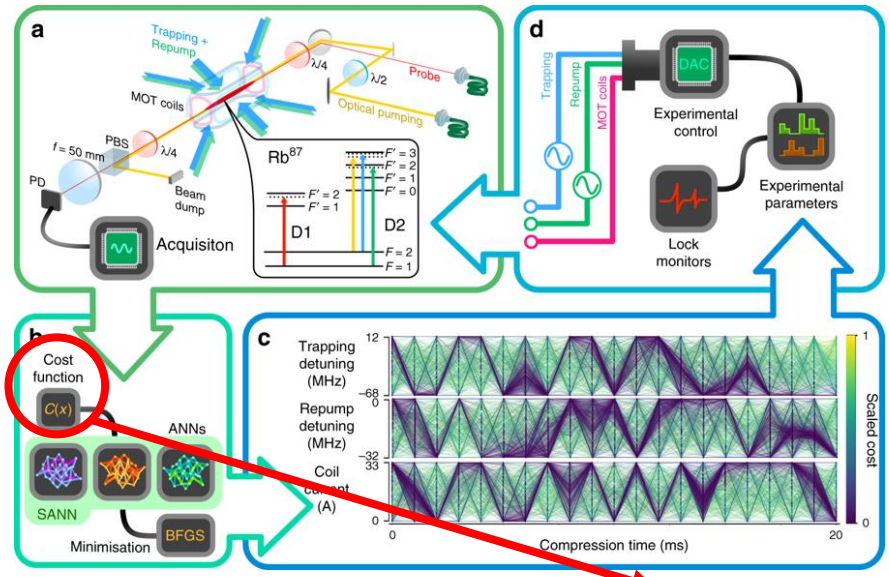
Magneto-Optical Trapping (MOT)

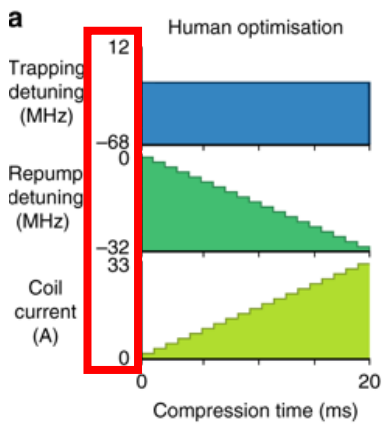
- To increase the optical depth(OD) of MOT, compression stage comes after ordinary MOT





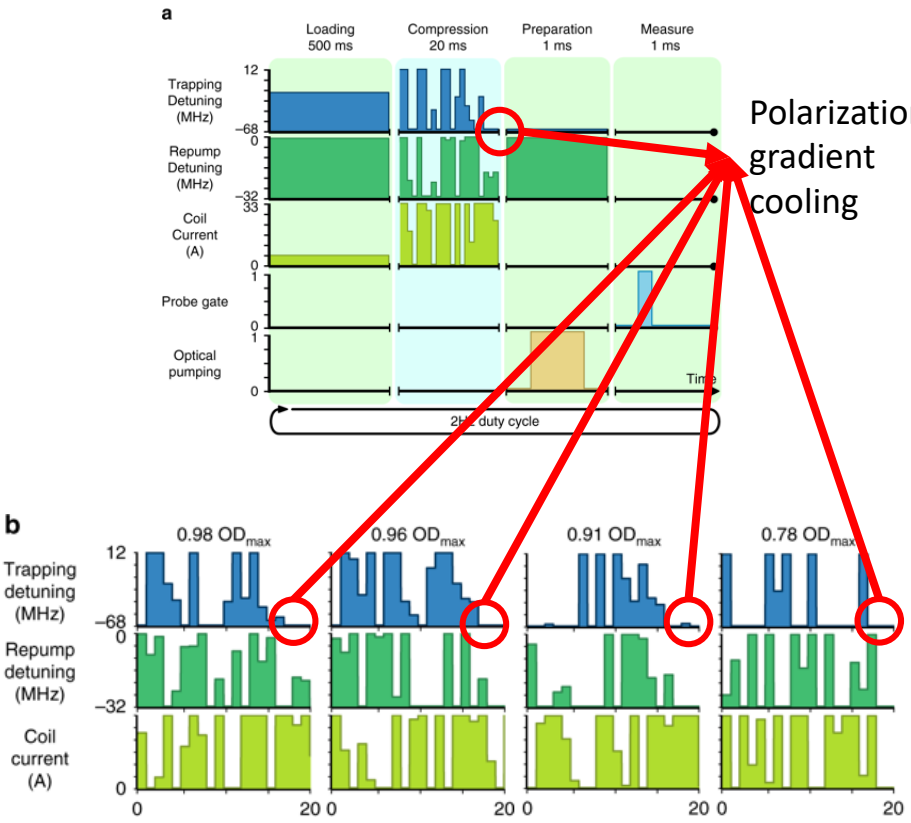
Experimental Scheme





$$C(X) = \frac{1}{P}\int_{t_i}^{t_f} p(t)dt$$

X : parameter set
P : scaling factor
p(t) : PD response



Polarization gradient cooling

- Optically pumping the ensemble into the F = 1 hyperfine ground state
- Turn off coil current to allow eddy currents to decay
- Equilibrium OD is achieved after 10 cycles
- Cost function is calculated after that

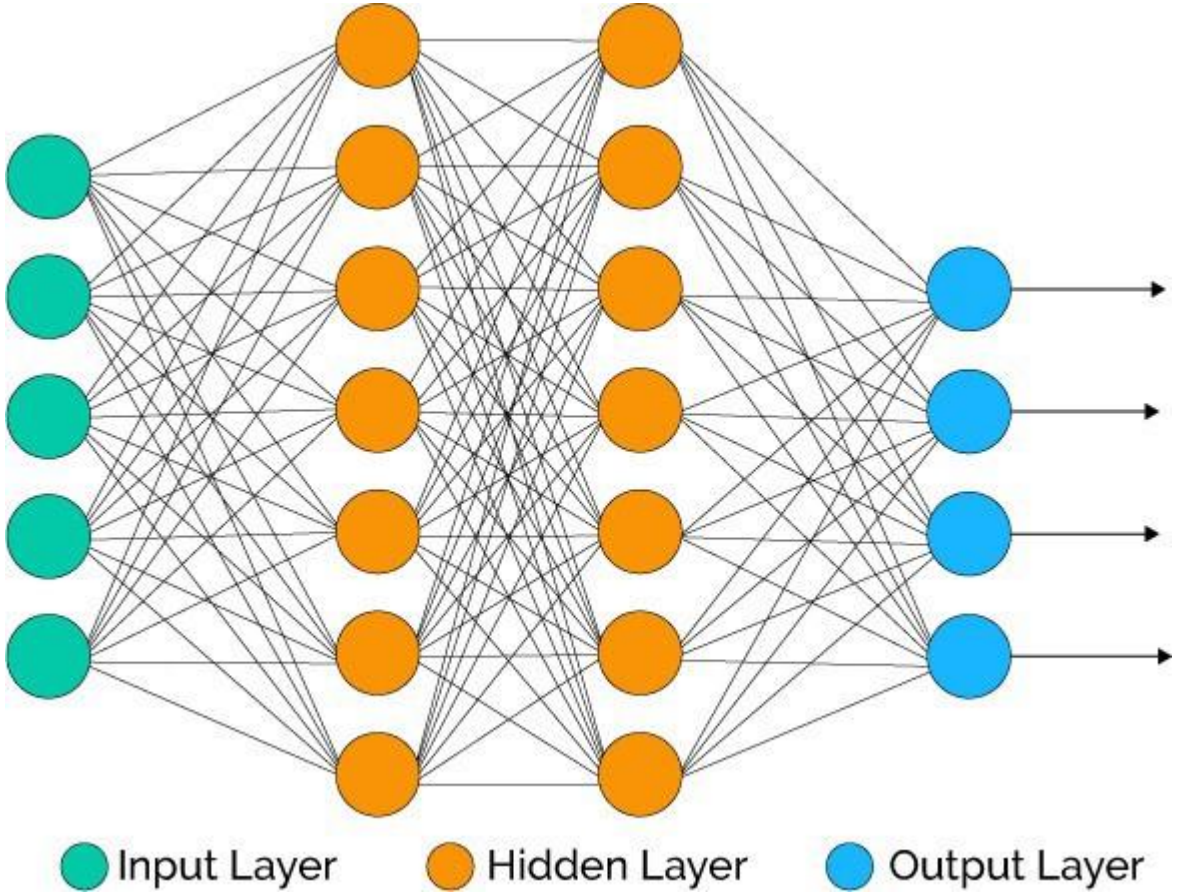
=> SANN's solution will reduce atom loss and maximize the compression

Artificial Neural Network (ANNs)

Trapping detuning

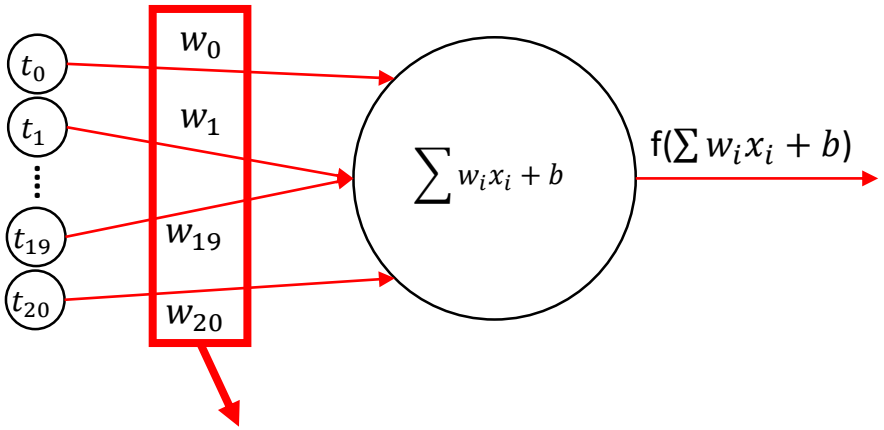
Repump detuning

Coil Currrent

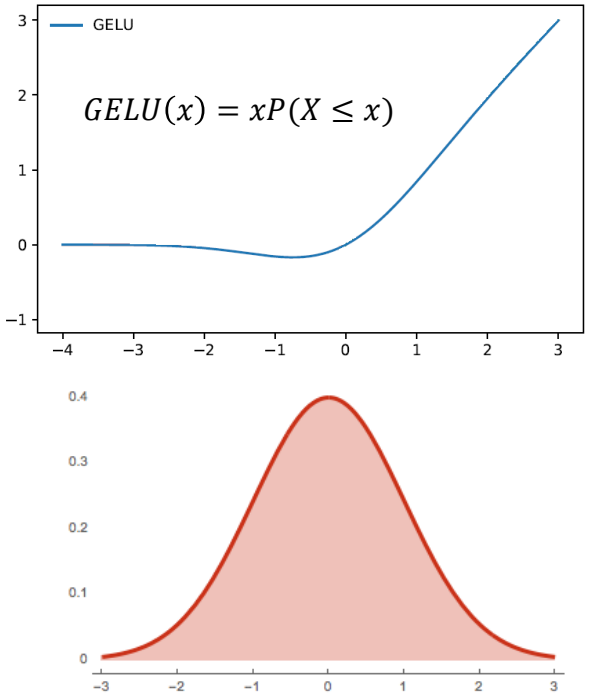


- ~ $2^{30} = 10^{9}$connections are computed by 2.67 GHz i7-920

Artificial Neural Network (ANNs)



Initialized using
He initialization



Trained by ***Adam algorithm***

$$w_t = w_{t-1} - \frac{\eta}{\sqrt{\hat{v}_t} + \varepsilon}\hat{m}_t$$

$$\hat{m}_t = \frac{m_t}{1-\beta_1^t} \quad \hat{v}_t = \frac{v_t}{1-\beta_2^t}$$

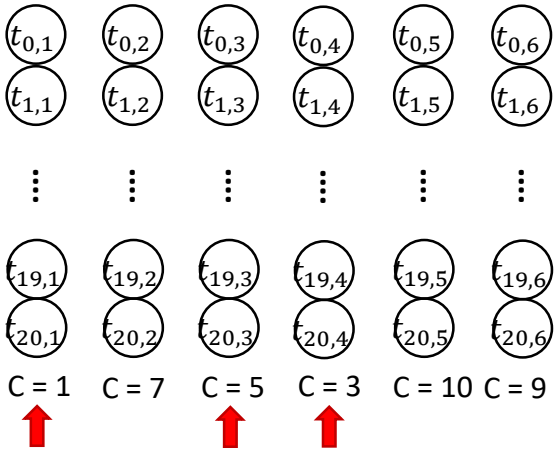
$$m_t = \beta_1 m_{t-1} + (1-\beta_1) g_t$$

$$v_t = \beta_2 v_{t-1} + (1-\beta_2) g_t^2$$

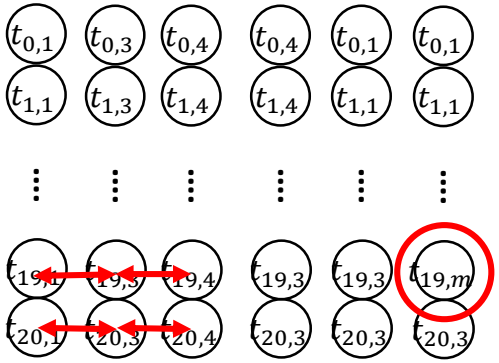
Adaptively change step size by previous information about amount and frequency of change

How to choose training sets?

Differential Evolution



Each parameter set has its own cost
Choose the parameter sets which have low costs

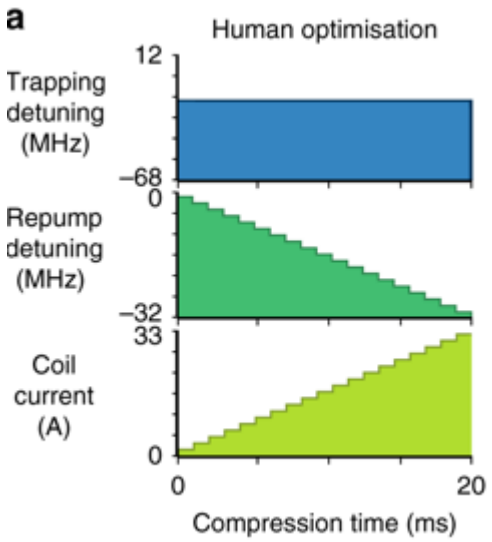


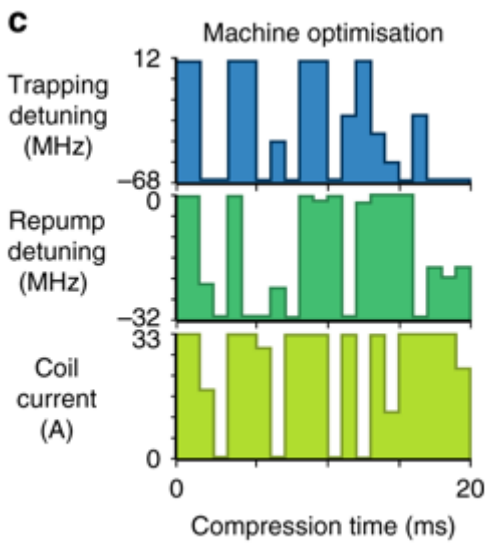
Chosen sets cross over their parameter at crossover rate(0.7)
Also mutation with random number occurs

Solutions from Human and ANN (1/2)

- Temporal dark SPOT
- Minimizing absorption of re-scattered photons by shelving atoms in a non-absorbing state

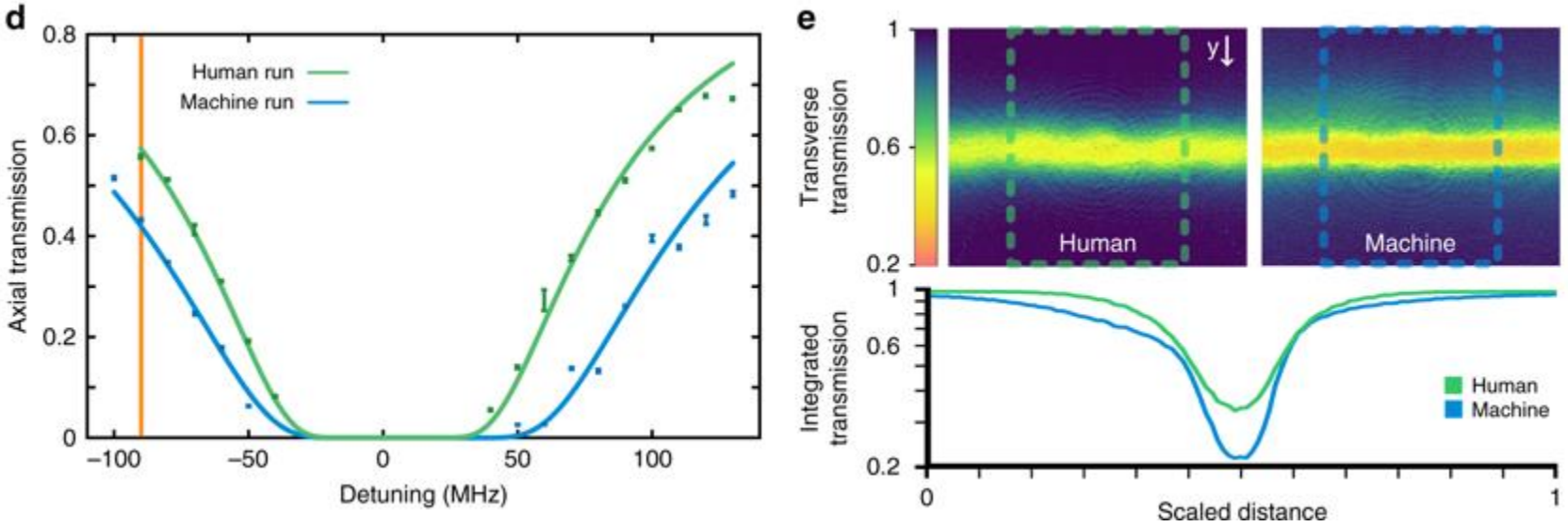
- Release-capture dynamics in optical lattice(Speculation)





Solutions from Human and ANN (2/2)

- $\frac{I_t}{I_0} = \exp(OD\,\frac{\gamma^2/4}{\Delta^2+\gamma^2/4})$
- Human : ANN = 535($\pm$8) : 970($\pm$20)
- Absorption image using an expanded beam on the repump transition 9 MHz detuned shows higher density of atoms in Machine solution



Cost landscape

- Smooth cost landscape suggests that the model is not overfit