HIGH PERFORMANCE CAPABILITIES

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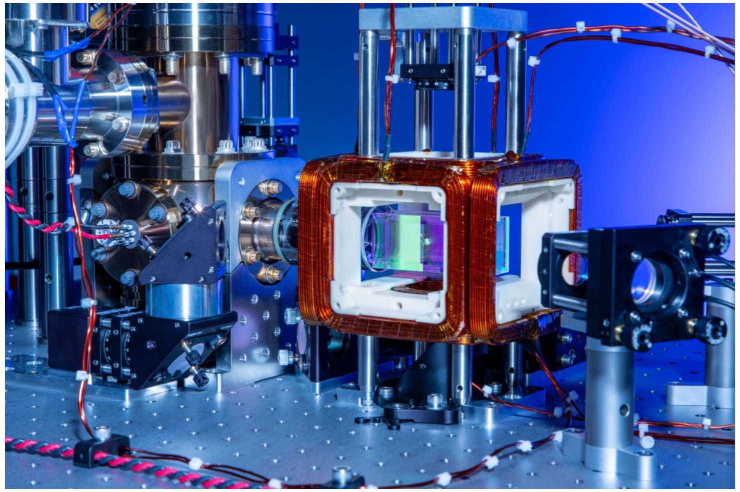
Recap

- Focused on ***Bloqade-to-Hardware*** **Pipeline**

$$\frac{H}{\hbar} = \sum_i \frac{\Omega(t)}{2}\left(e^{i\phi(t)}|g_i\rangle\langle r_i| + e^{-i\phi(t)}|r_i\rangle\langle g_i|\right) - \sum_i \Delta_\mathrm{i}(t)n_i + \sum_{i<j} V_{ij}n_in_j$$



Recap (Cont.)

- 1. **Define** your problem
  - If you can, perform emulation!
- 2. **Transform** to Hardware
- 3. **Validate**
- 4. **Tweak** problem (if necessary)
- 5. **Submit**!
- 6. **Retrieve** data

Learning Objectives

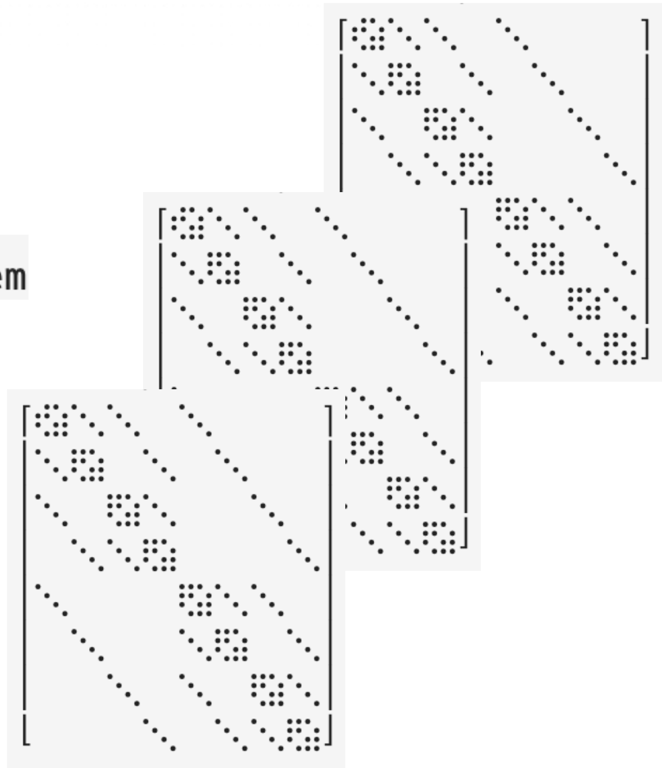
- **Explain** how Bloqade's tools for high performance work
- **Execute** dynamics simulations using Blockade Subspace, Multithreading, and GPU support
- **Critique** the benefits and drawbacks of each method

Bird’s Eye View

- Let’s look under the hood

$$i\hbar \frac{\partial}{\partial t}|\psi\rangle = \hat{\mathcal{H}}(t)|\psi\rangle$$

`SchrodingerProblem`



$$\begin{aligned}
y_{n+1} &= y_n + h\sum_{i=1}^{s} b_i k_i \\
k_1 &= f(t_n, y_n), \\
k_2 &= f(t_n + c_2 h, y_n + h(a_{21}k_1)), \\
k_3 &= f(t_n + c_3 h, y_n + h(a_{31}k_1 + a_{32}k_2)), \\
&\ \ \vdots \\
k_i &= f\left(t_n + c_i h, y_n + h\sum_{j=1}^{i-1} a_{ij}k_j\right).
\end{aligned}$$

Can We Optimize This?

- *Memory Efficiency*
  - **Blockade Subspace**
- *Execution Efficiency*
  - **Multithreading**
  - **GPU support**

Blockade Subspace

- Key Idea: entire 2^n state space unnecessary
- If two atoms blockade each other, probability of reaching double Rydberg Excitation state impossible
- Can get rid of these states but should take care in potentially dropping non-trivial contributions to dynamics

Multiple Dispatch for Performance

- Targeting repeated solver calls (lots of Matrix-Vector multiplication)
- Reduce memory footprint as much as possible with ”sparsest” possible matrix formats
- Take advantage of *Multiple Dispatch* to **define Matrix–Vector multiplication optimized for different matrix types!**
- Also lets us perform **Matrix-Vector multiplication with different backends** (Custom CPU approaches and simple GPU support)

```
= PermMatrix([2, 1, 3], T[1, 1, 0])
= PermMatrix([1, 3, 2], T[0, 1, 1])

= Diagonal(T[1, -1, 0])
= Diagonal(T[0, 1, -1])

= sparse([2], [2], T[1], 3, 3)
= sparse([3], [3], T[1], 3, 3)
```

Multithreading

- Handled by **BloqadeExpr**

- Two different backends to be aware of

    - **ThreadedSparseCSR** – Naïve Sparse-Matrix Vector multiplication, good for balanced matrices
        - Little to no overhead (other than threads) but could have longer run time

    - **ParallelMergeCSR –** Based on Merrill and Garland's algorithm (10.1109/SC.2016.57), good for unbalanced matrices
        - Pay some upfront cost but ensure optimally balanced load across threads

- Balance – number of nonzero entries per row of Matrix

    - Can be unbalanced if you add phase or use subspace

    - Documentation can be found here: https://queracomputing.github.io/Bloqade.jl/dev/multithreading/

GPU Support

- Take advantage of **CUDA.jl**
- Additional step of loading and unloading from the GPU
- Keep in mind:
  - Now restricted to GPU memory
  - Loading and Unloading incurs some overhead

Conclusion

- Recap Learning Objectives:
  - **Understand** how Bloqade's tools for high performance work
  - **Compute** dynamics using Blockade Subspace, Multithreading, and GPU support
  - **Observe** the benefits and drawbacks of each method