Versatile CPS For Data Center Cooling

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Outline

- Motivation
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  - Two-Aisle Model
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- Conclusion

Motivation

As we need more computing powers, optimizing energy usage and efficiency is very important.

When the safety of the equipment and operation is paramount, it's good to have a formal proof for its safety.

Motivation, Related Works

Optimizing cost based on current electricity cost[Wang 2014]

Change air intake source to achieve optimal cooling efficiency. [Mansousakis 2016]

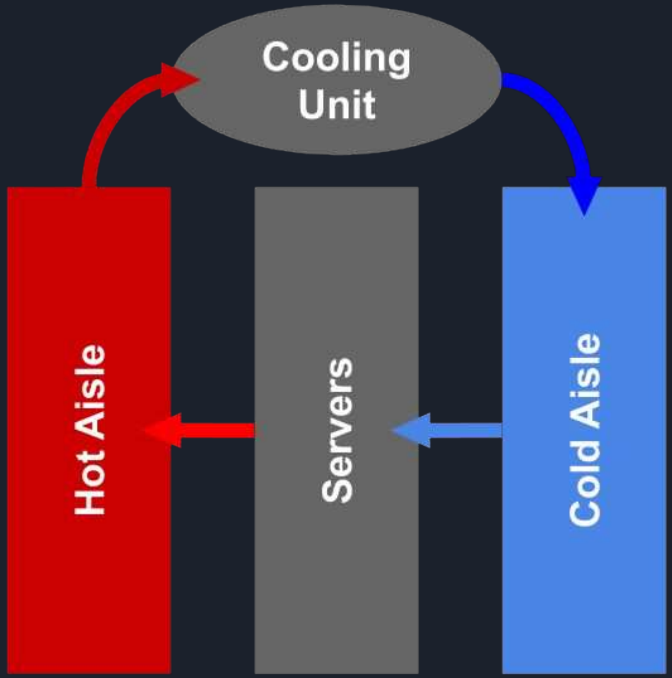
Use neural network frame to predict power usage effectiveness and optimizing cooling base [Yao 2016]

Motivation, Related Works

Distinct things that we want to focus:

- Hybrid system modeling the temperature and energy in cooling system.
- Formal differential dynamic logic proof of safety of operation.
- Runtime safety system that could be used in conjunction with a wide-variety of "optimized" controllers.

Two-Aisle Model



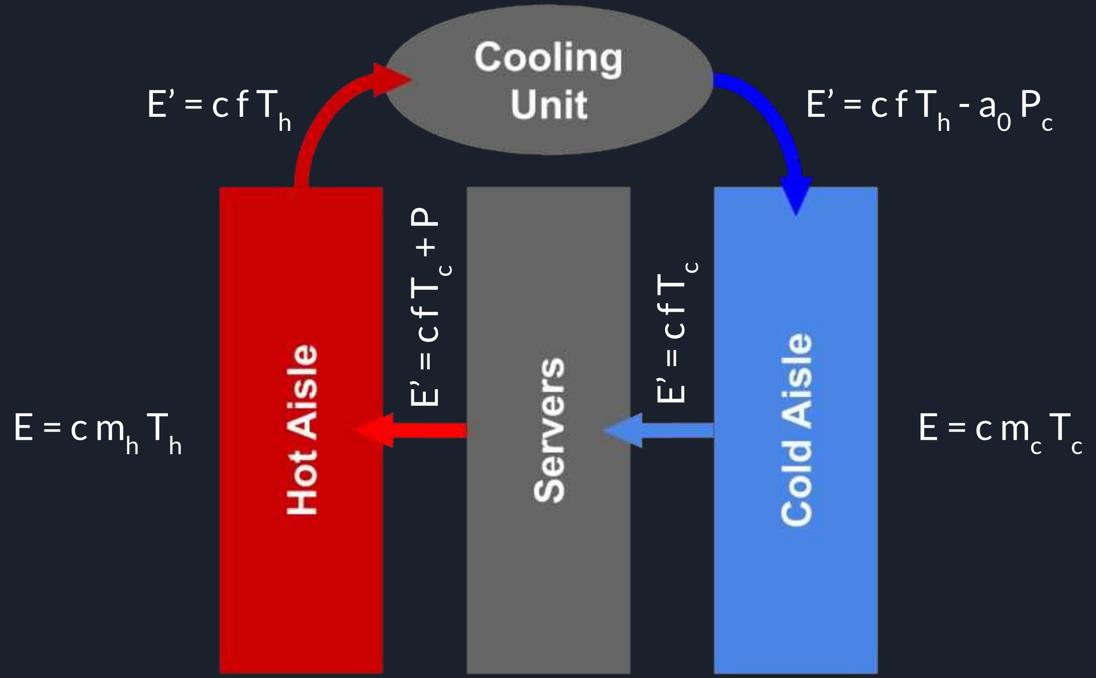
- Thermal energy inside the datacenter
  - Enters at servers
  - Removed at cooling unit

- Aisles account for all of the thermal mass

- Circulating air moves energy through system

- Controller controls power usage of cooling unit and air circulation speed

Physics Model



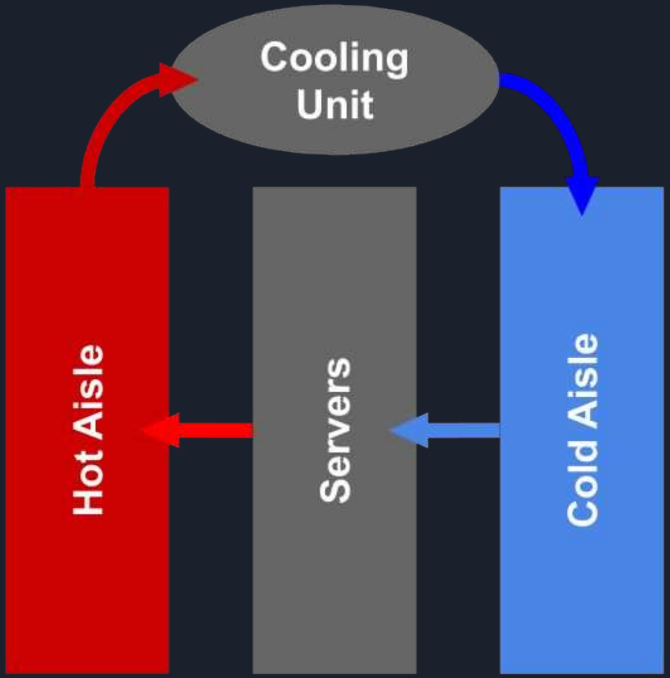
$$T'_c = \frac{f(T_o - T_c)}{m_c}$$

$$T'_h = \frac{f(T_c - T_h)}{m_h} + \frac{P}{c\,m_h}$$

$$T'_o = \frac{f(T_c - T_h)}{m_h} + \frac{P}{c\,m_h}$$

Key Properties

- Thermal energy of system remains below an equilibrium point
  - Bounds the problem
  - Useful for proving other properties
- Cold aisle cooler than hot aisle
  - More complicated to prove than expected
  - Relationship can be leveraged for proofs
- **Cold aisle cooler than desired safety temperature**
  - Very difficult: outlet temperature and cold aisle temperature can invert
  - Implies a max temperature for hot aisle



Key results

- Proved safety property for a simple single-aisle system
- Proved some properties (but not safety) for a double-aisle system with a very simple controller
  - Complex relationships among multiple variables
  - Likely needs additional invariants

Future Work

- Complete proof and prototype a monitor
  - Combine with machine learning controllers
  - Verify model's usefulness on real data
- Make the controller more permissive
- Improve the model's accuracy
  - Distributed Server Model
  - More inputs
  - More complex physics

Conclusion

- Formal verification of a monitor complements current machine learning approaches well
- Proofs for even simple real-world models can be complicated and require significantly more work
- Differential dynamic logic is good for guaranteeing safety properties

Thank you!