Versatile CPS For Data Center Cooling

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Outline

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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

\[ E = c m T \]

\[ E' = cf T_h \]

\[ E' = cf T_c - a_0 P_c \]

\[ E = cm_h T_h \]

\[ E' = cf T_c + P \]

\[ T_c' = \frac{f(T_o - T_c)}{m_c} \]

\[ T_h' = \frac{f(T_c - T_h)}{m_h} + \frac{P}{cm_h} \]

\[ T_o' = \frac{f(T_c - T_h)}{m_h} + \frac{P}{cm_h} \]
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!