Cyber-Physical Systems

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Stochastic (Hybrid) Systems

Probabilistic Models

- Models for components that we studied so far were either deterministic or nondeterministic.
- The goal of such models is to represent computation or time-evolution of a physical phenomenon.
- These models *do not* do a great job of capturing uncertainty.
- We can usually model uncertainty using probabilities, so probabilistic models allow us to account for likelihood of environment behaviors
- Machine learning/AI algorithms also require probabilistic modelling!

Stochastic Difference Equation Models

- We assume that the plant (whose state we are trying to estimate) is a stochastic discrete dynamical process with the following dynamics:

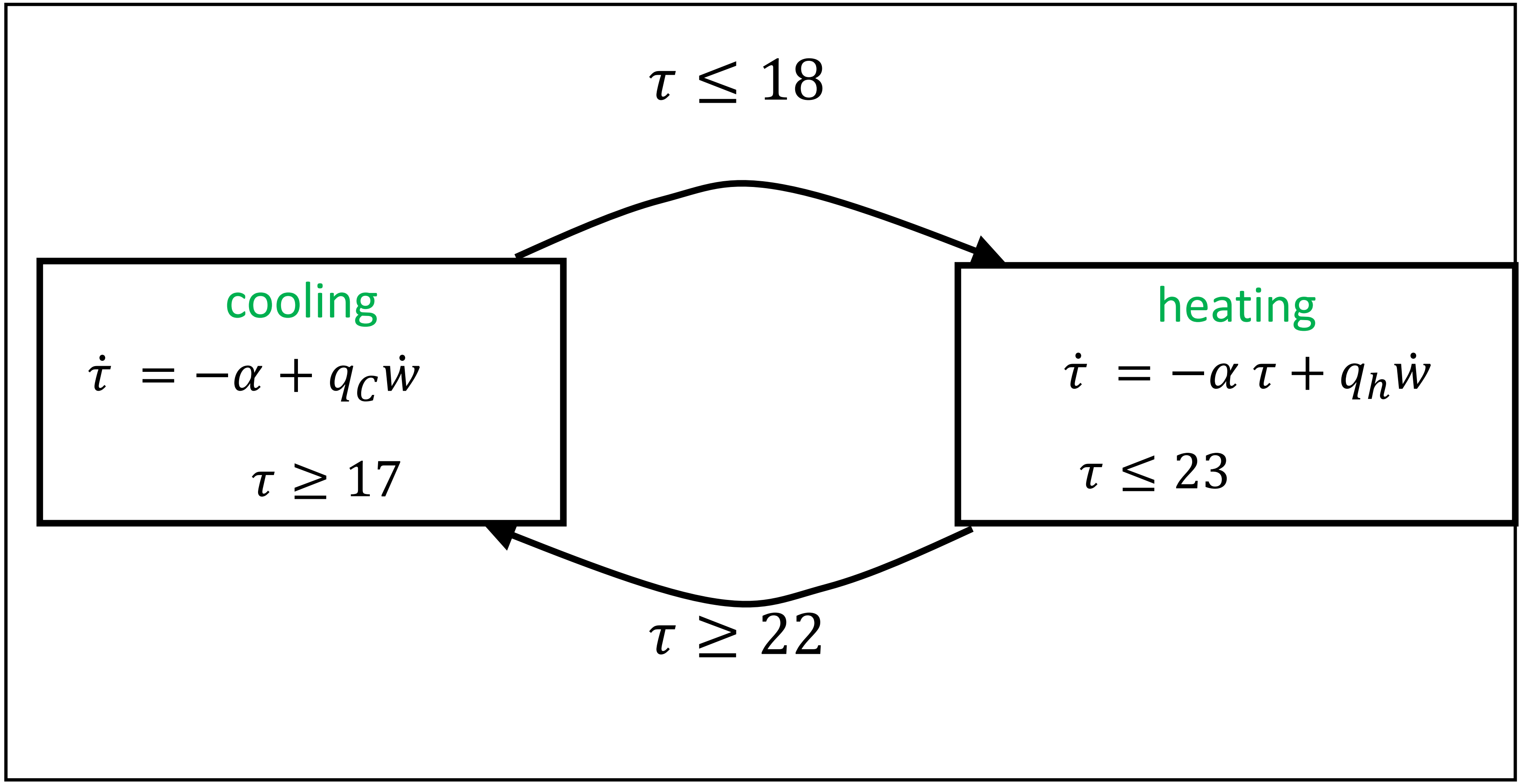
$$\mathbf{x}_k = A\mathbf{x}_{k-1} + B\mathbf{u}_k + \mathbf{w}_k \text{ (Process Model)}$$

$$\boldsymbol{y}_k = H\mathbf{x}_\mathrm{k} + \mathbf{v}_k \text{ (Measurement Model)}$$

$\mathbf{x}_k, \mathbf{x}_{k-1}$	State at time k,$k-1$
$\mathbf{u}_k$	Input at time k
$\mathbf{w}_k$	Random vector representing noise in the plant, $\mathbf{w} \sim N(\mathbf{0}, Q_k)$
$\mathbf{v}_k$	Random vector representing sensor noise, $\mathbf{v} \sim N(\mathbf{0}, R_k)$
$\boldsymbol{y}_k$	Output at time k

n	Number of states
m	Number of inputs
p	Number of outputs
A	$n \times n$ matrix
B	$n \times m$ matrix
H	$p \times n$ matrix

Example



$\tau \leq 18$
cooling
$\dot{\tau} = -\alpha + q_C \dot{w}$
$\tau \geq 17$
heating
$\dot{\tau} = -\alpha\,\tau + q_h \dot{w}$
$\tau \leq 23$
$\tau \geq 22$

The Family of Markov Models

<table>
<tr><td colspan="2" rowspan="2">Markov Models</td><td colspan="2">Do we have control over the state transitions?</td></tr>
<tr><td>No</td><td>Yes</td></tr>
<tr><td rowspan="2">Are the states completely observable?</td><td>Yes</td><td>MC
Markov Chain</td><td>MDP
Markov Decision Process</td></tr>
<tr><td>No</td><td>HMM
Hidden Markov Model</td><td>POMDP
Partially Observable Markov Decision Process</td></tr>
</table>

The Memoryless Property

$$p(s_{t+1}|s_{1:t}) = p(s_{t+1}|s_t).$$

The knowledge of the state s_t captures the complete information capturing all the relevant information about the present and the past of the system necessary for predicting its future evolution