Methods for Sensor Based Farrowing Prediction and Floor-heat Regulation

The Intelligent Farrowing Pen

Ph.D. Dissertation

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Objective

To develop and validate an automated system that

- monitors the pre-parturition behaviour of the sow in the farrowing pen,
- predicts the onset of farrowing
- would further help the farm manager to optimize the decisions related to parturition and post-parturition - e.g. optimal floor-heat regulation system

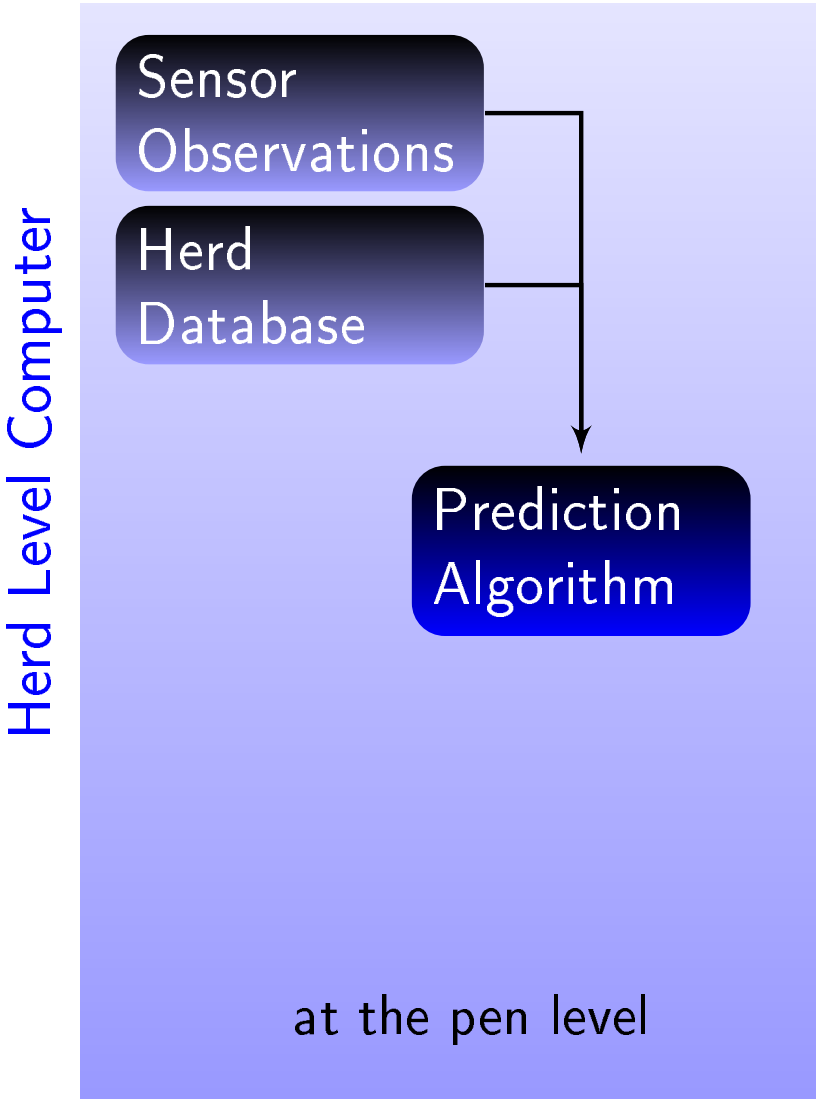
by integrating several sensor information

purpose

"to reduce the piglet mortality"

*Study was supported by The Danish National Advanced Technology Foundation

Overview of the Study



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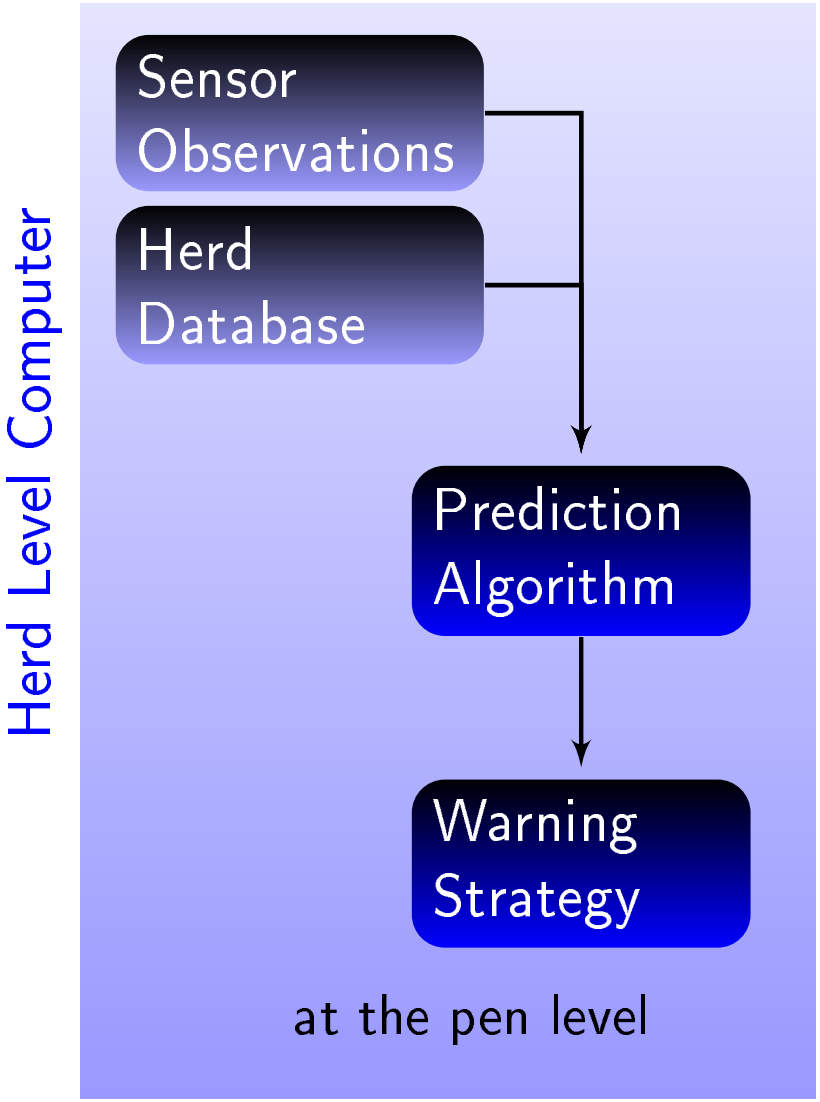

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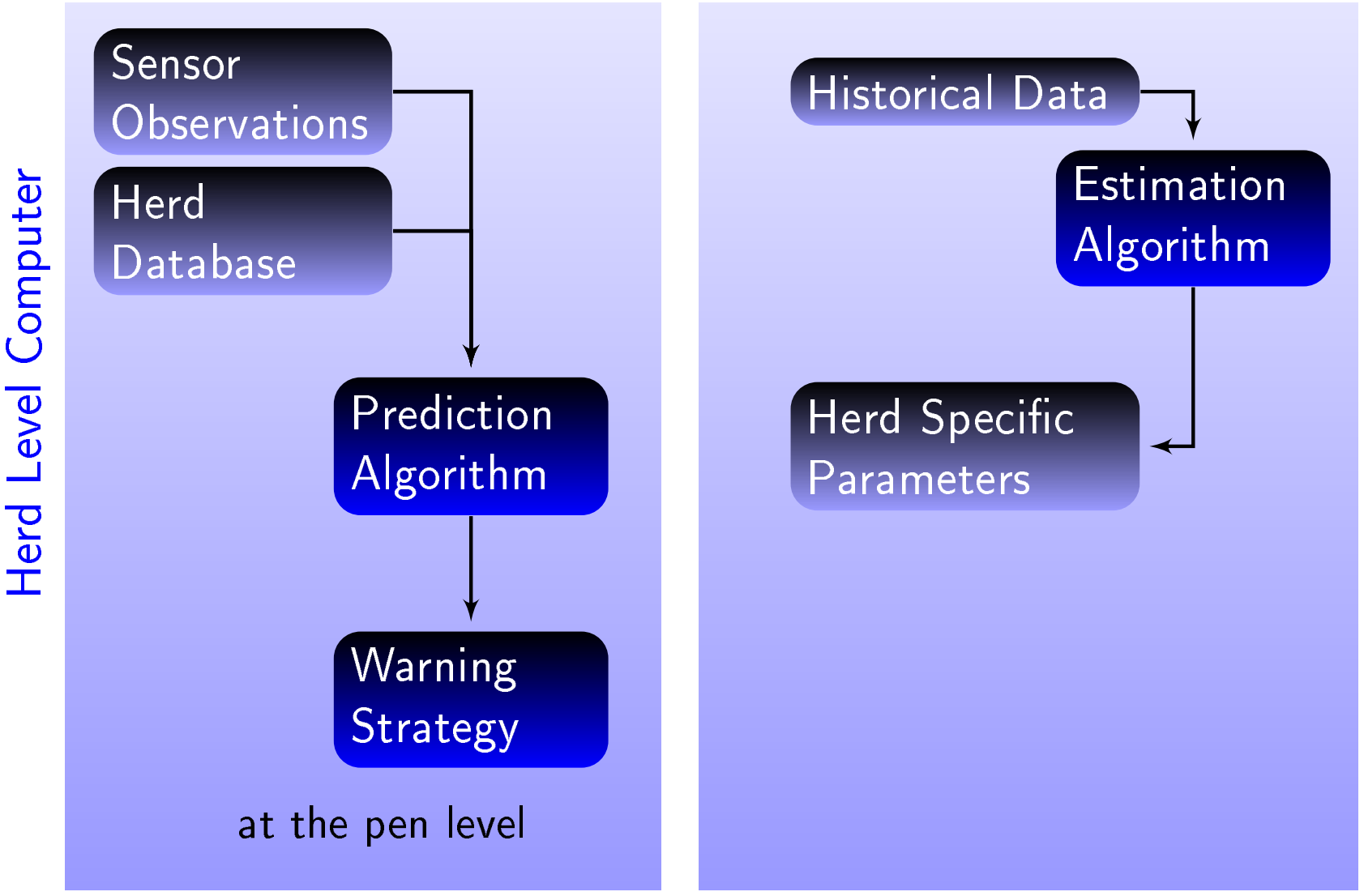

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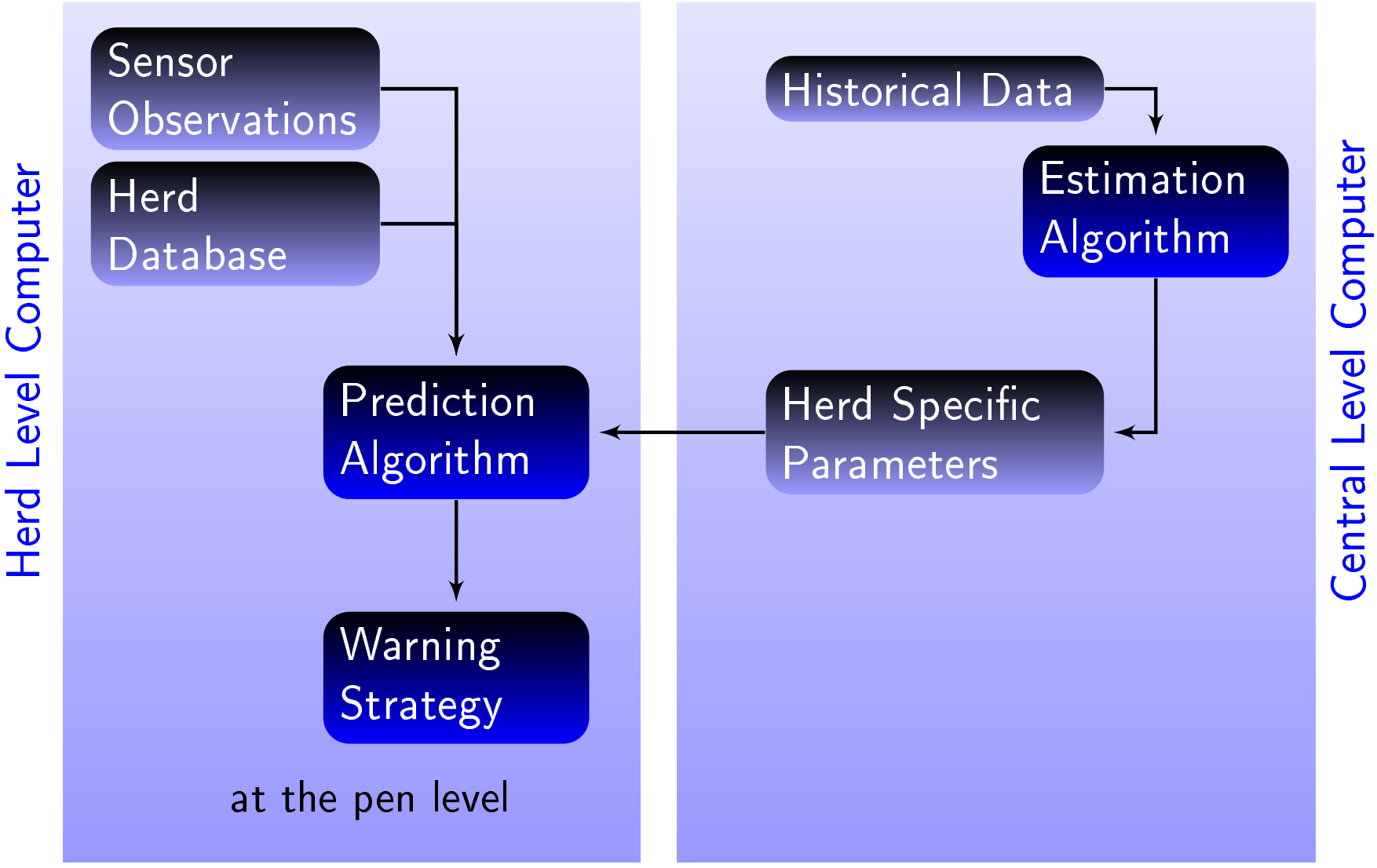

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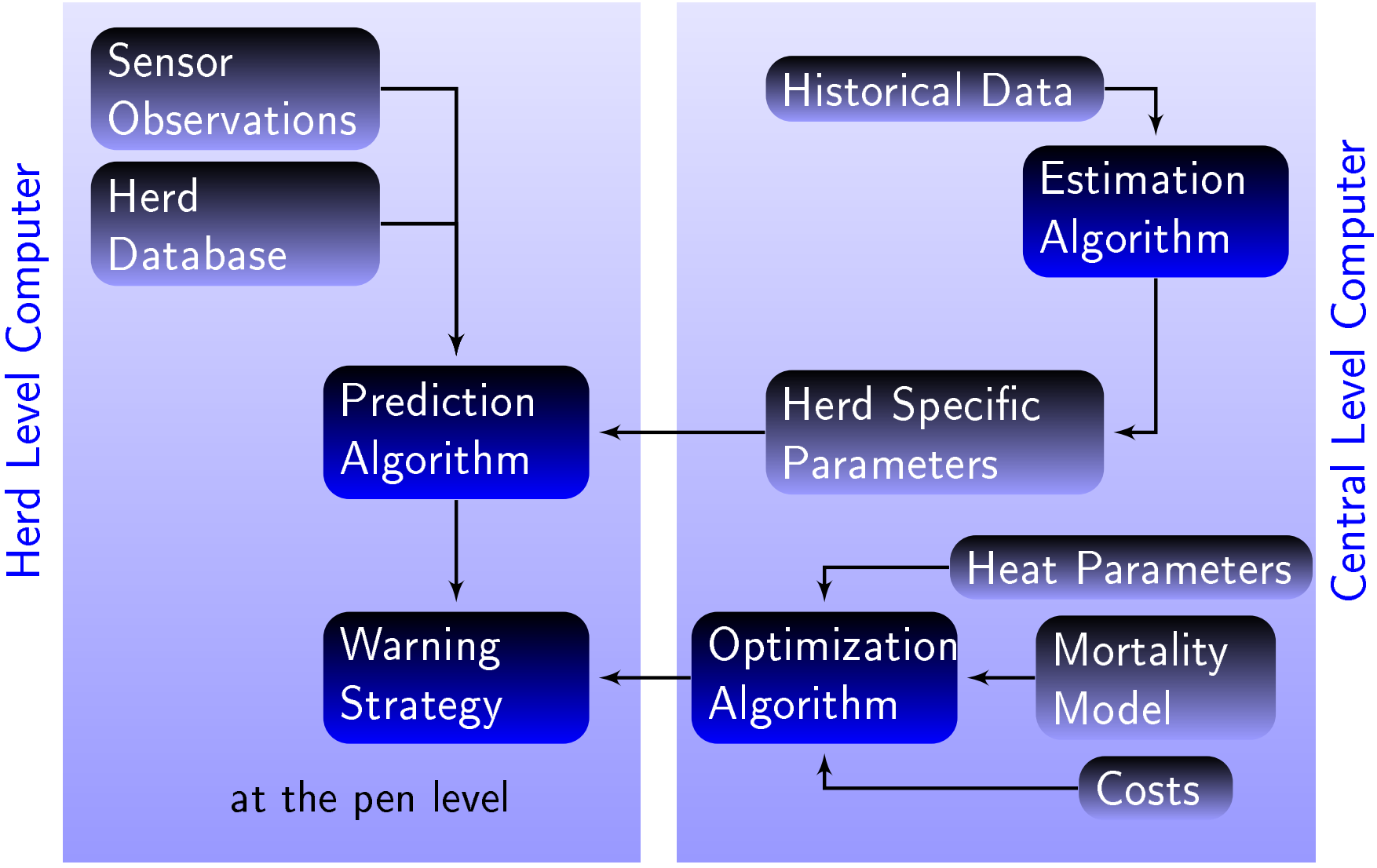

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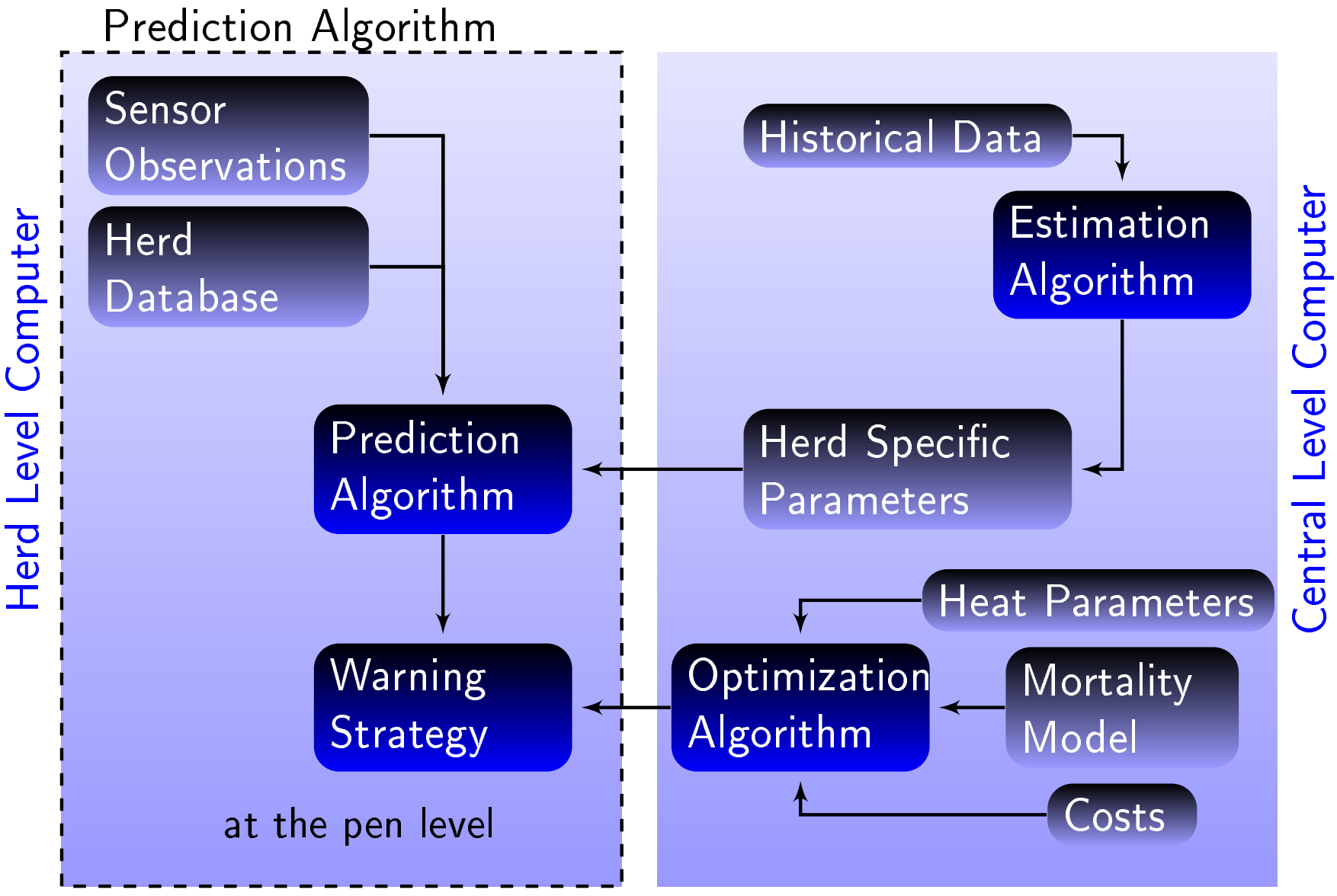

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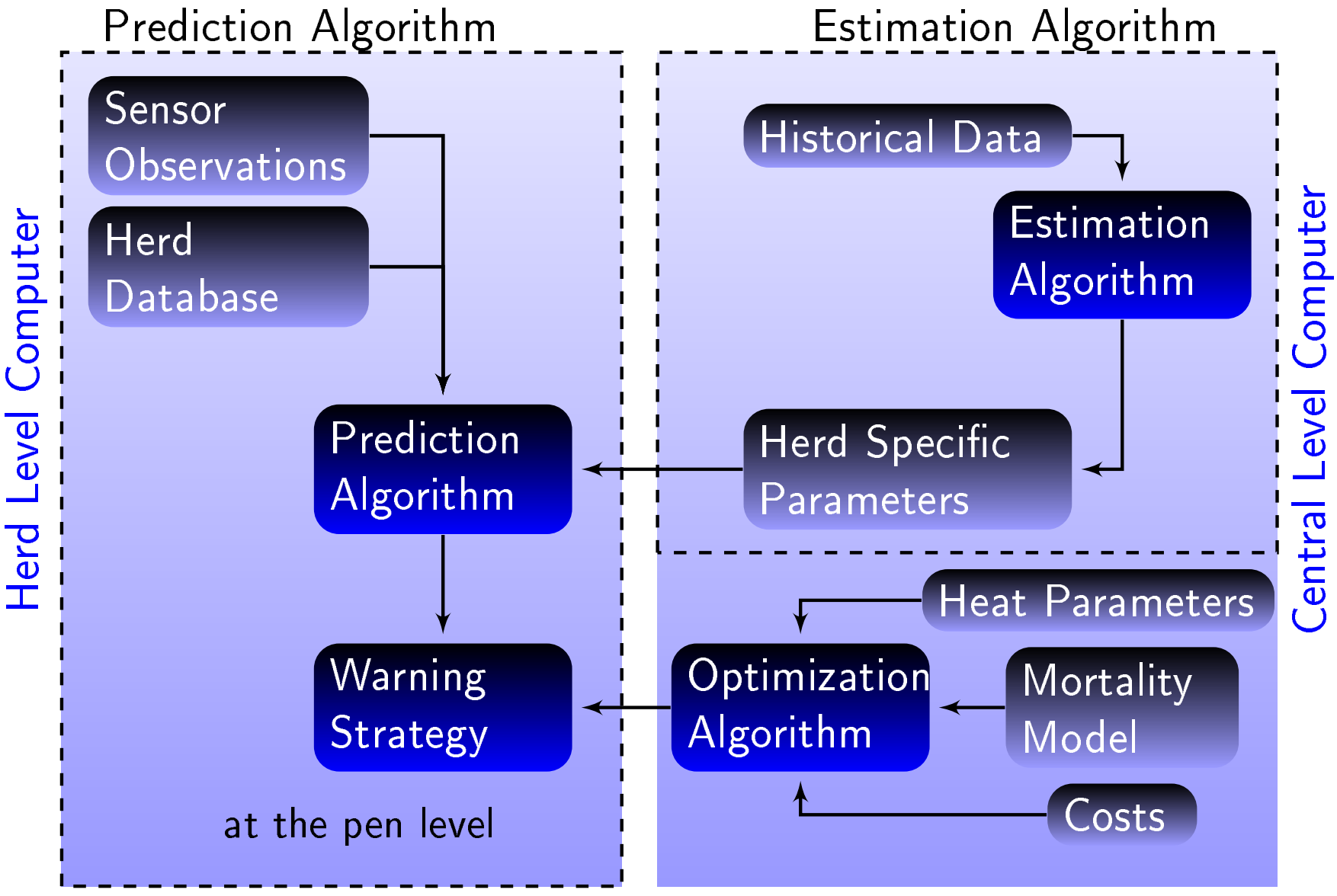

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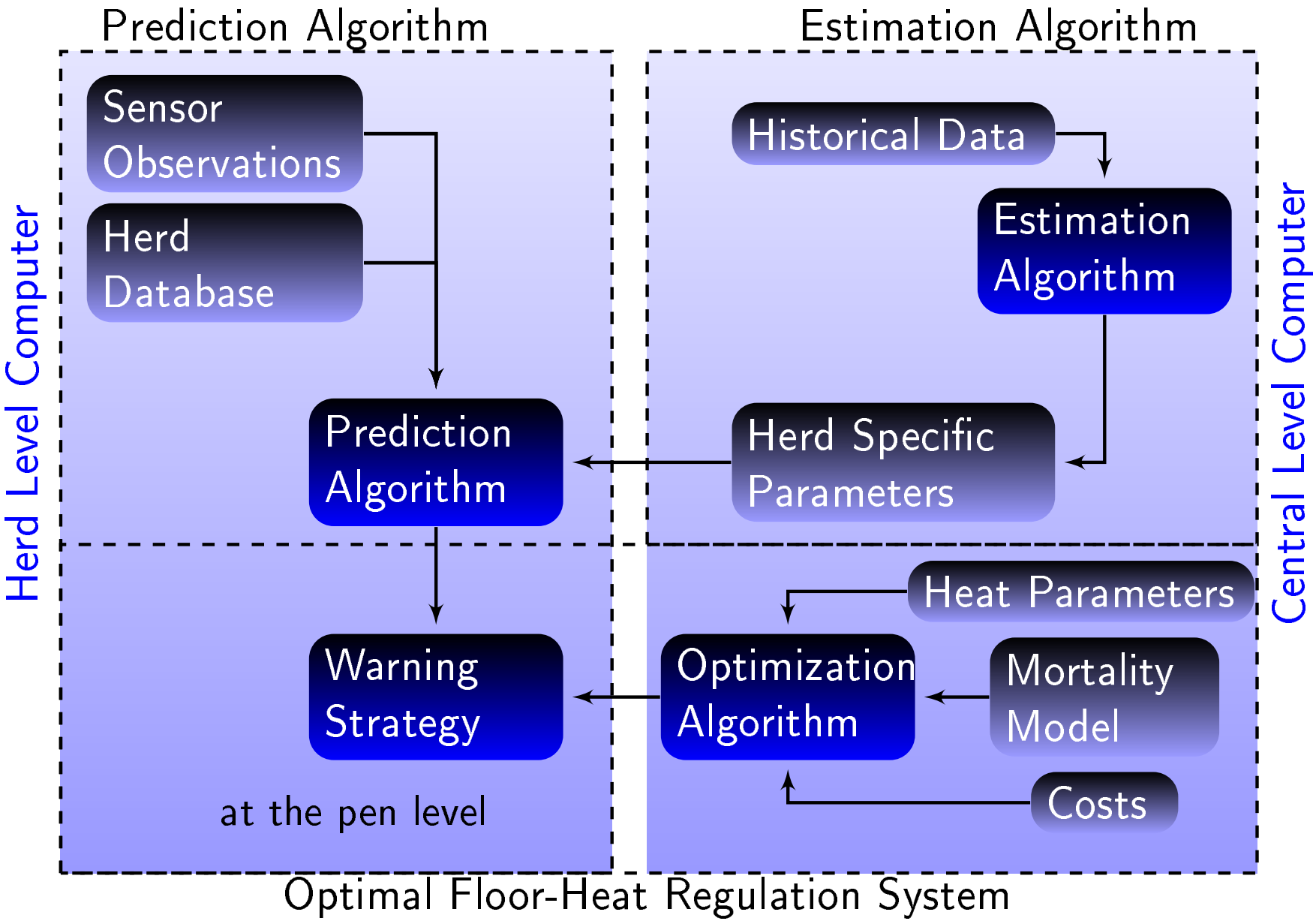

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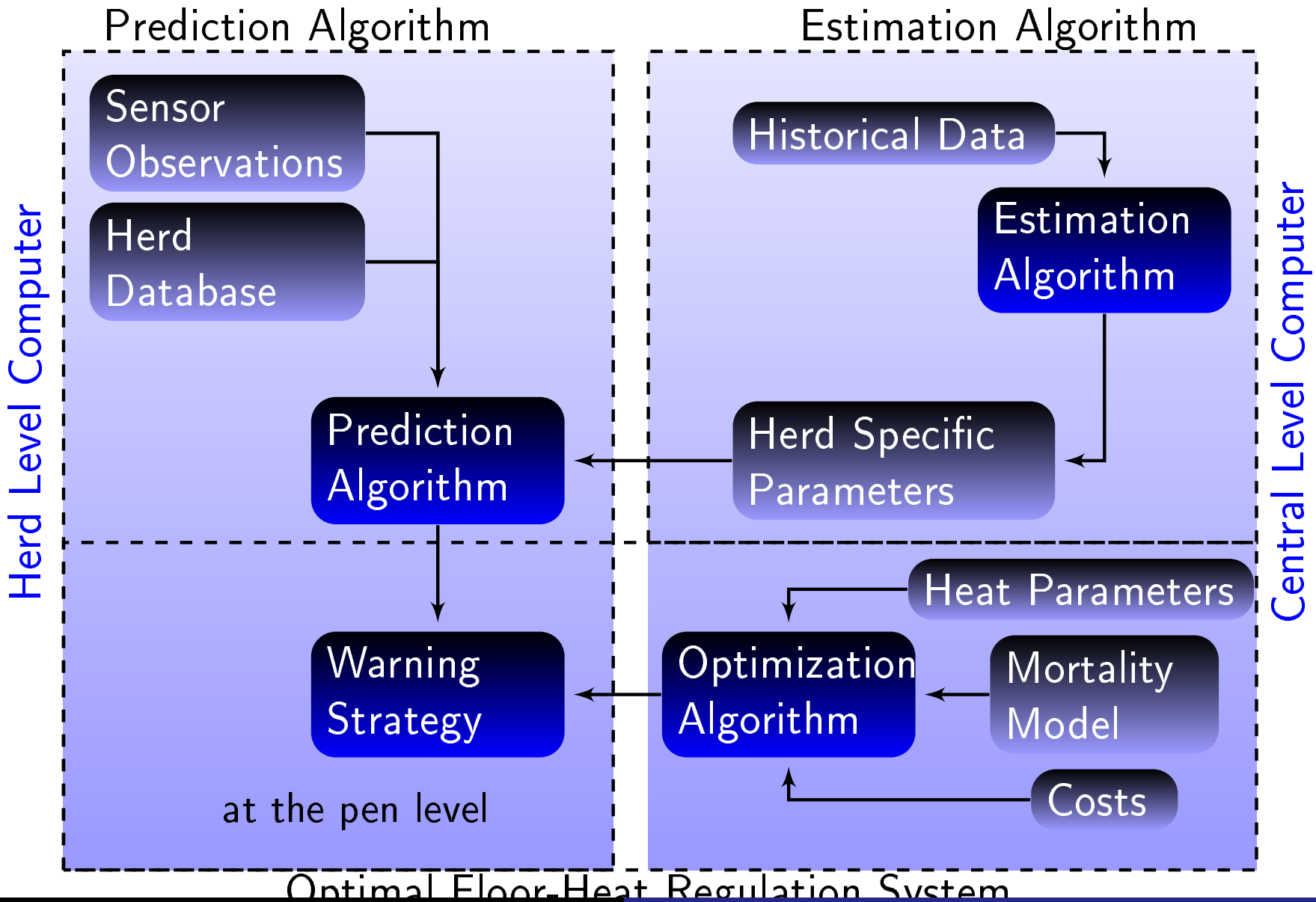

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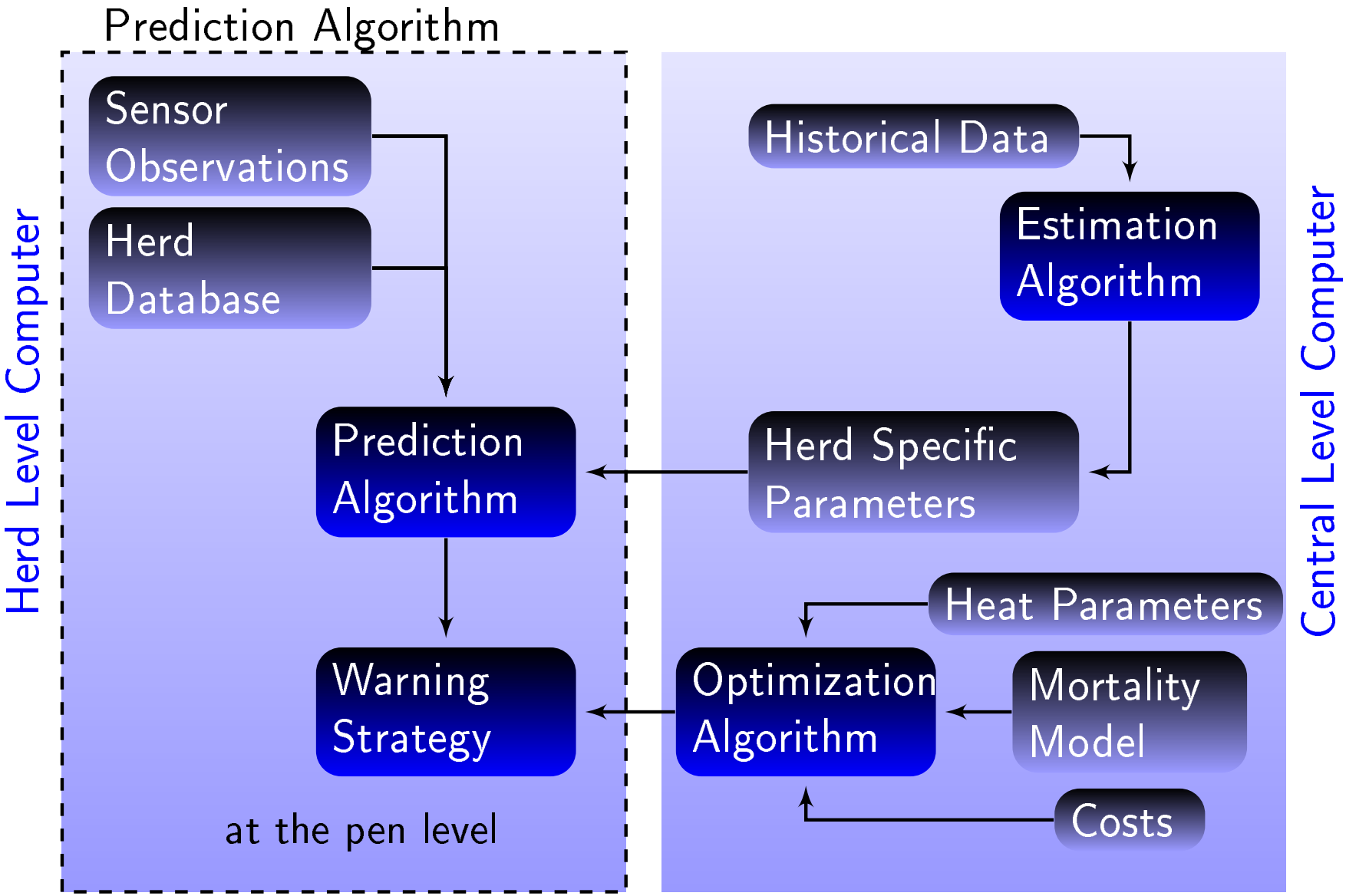
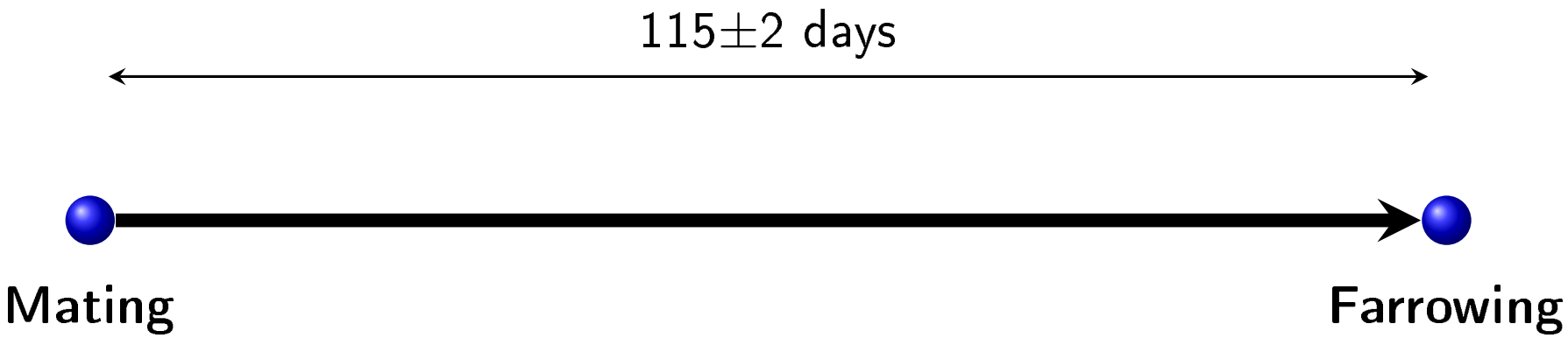


Gestation Period

Behavioural States



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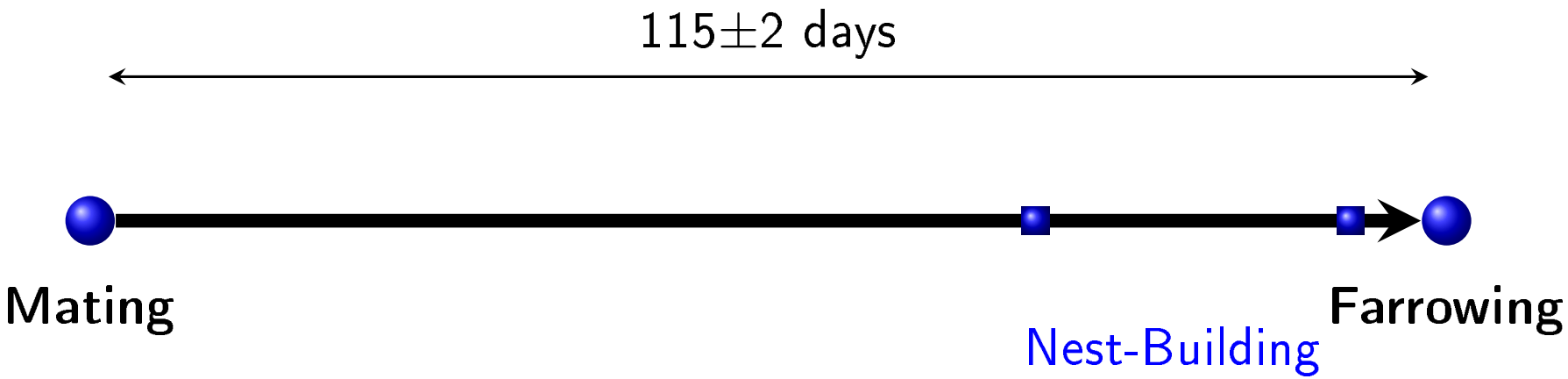

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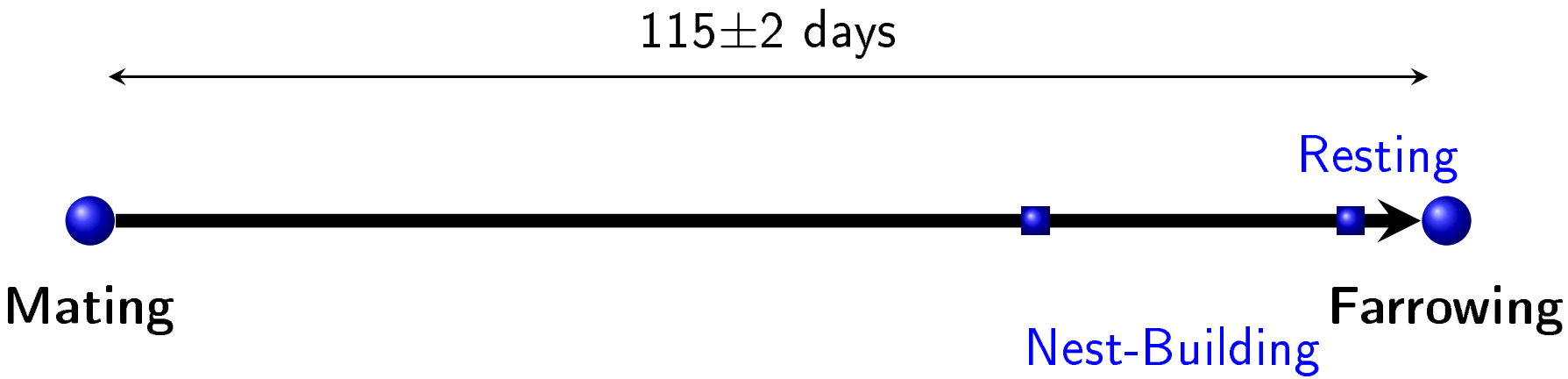

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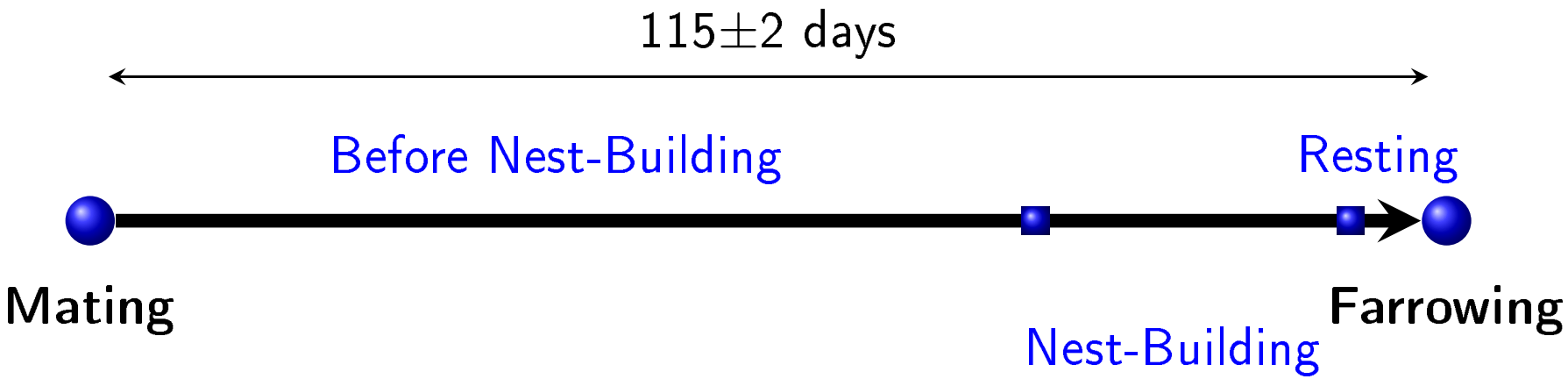

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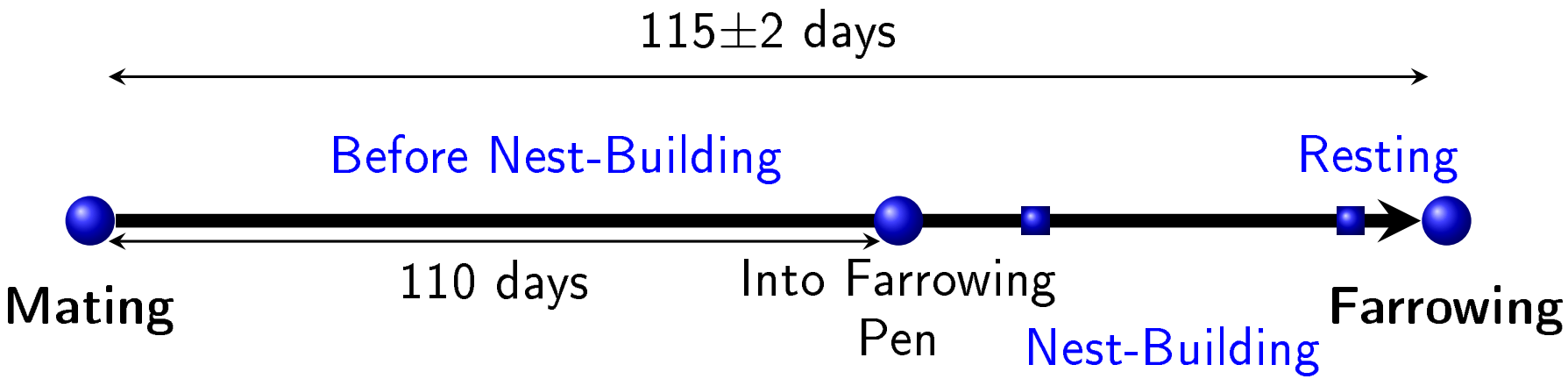
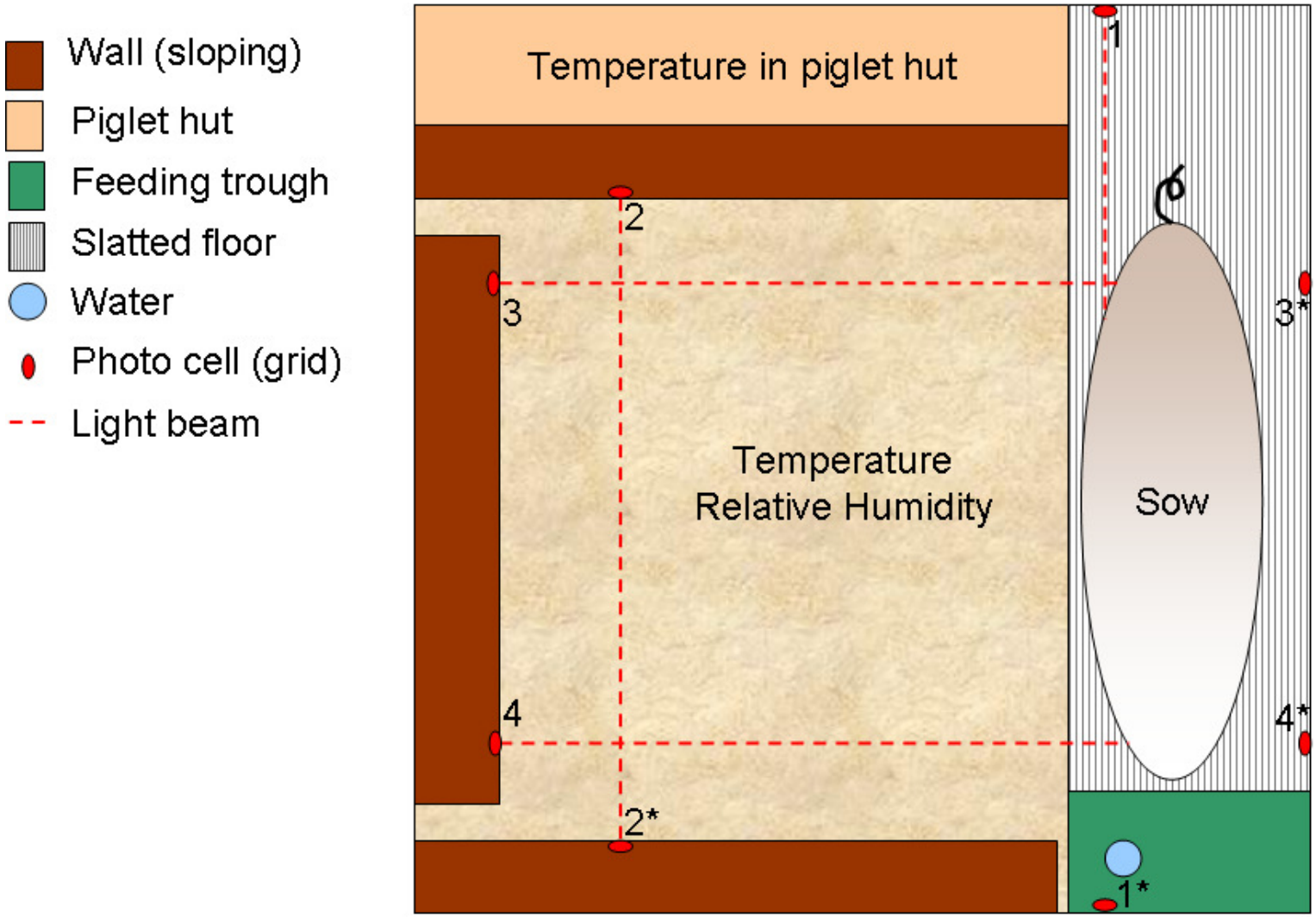


Farrowing Pen

Number of sows observed: 64

Sensor set-up at the pen level

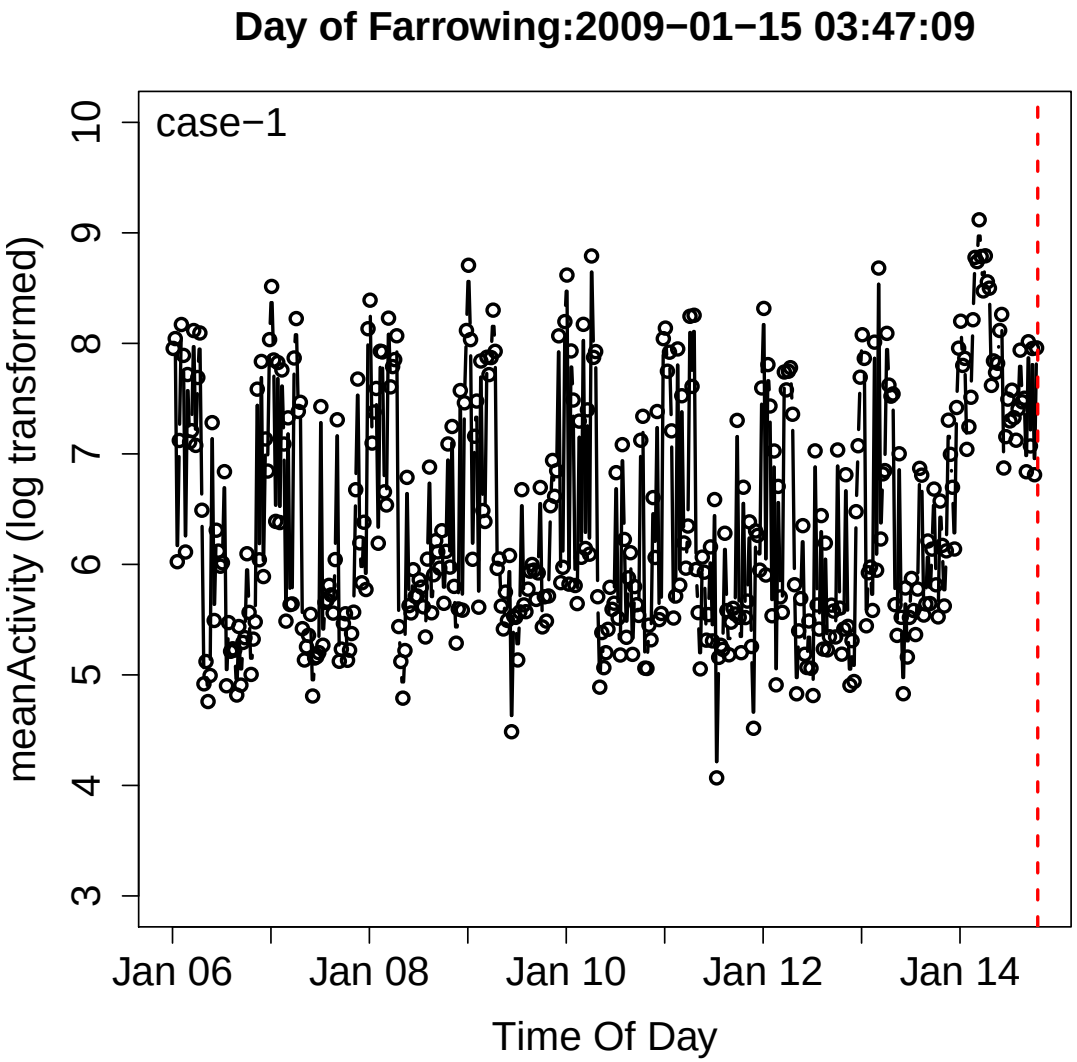
Number of sows observed: 64



Online Recording of Sensor Observation for a Sow - An idea

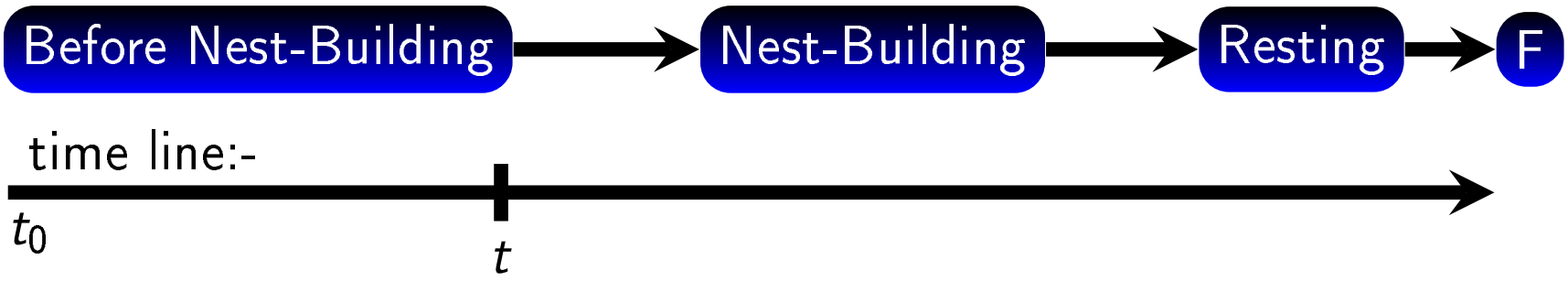
Water consumption

Sensor observation for a sow - meanActivity



"Farrowing process" as a Markov Model

Farrowing process - continuous time



$\mathbf{T}_t$: remaining time to onset of farrowing

✓ Stochastic process

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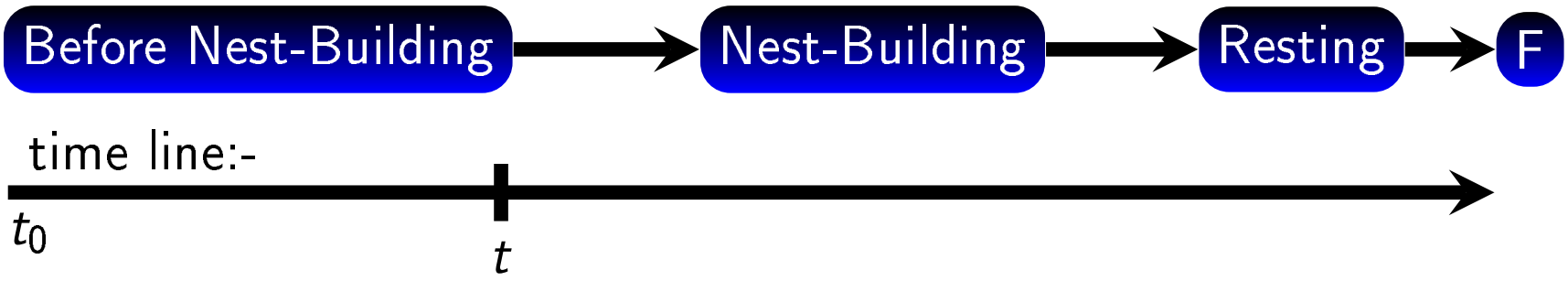

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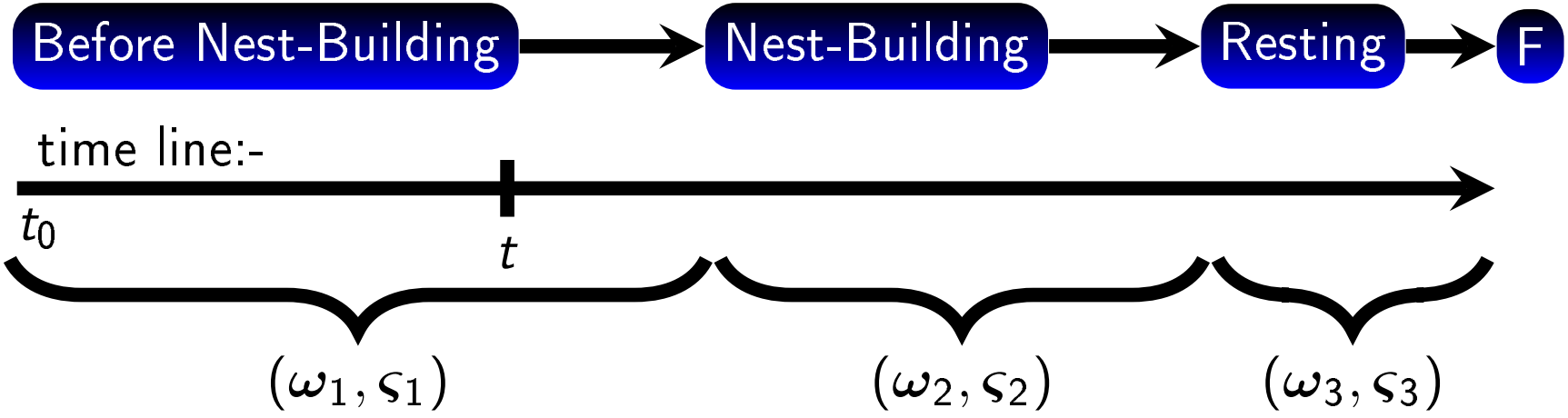

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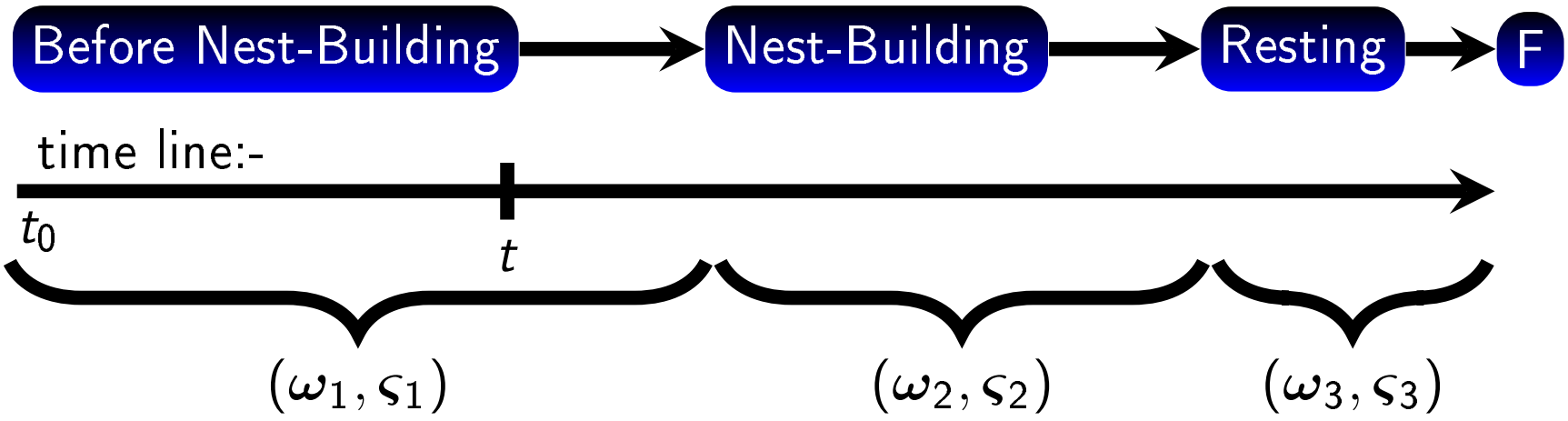

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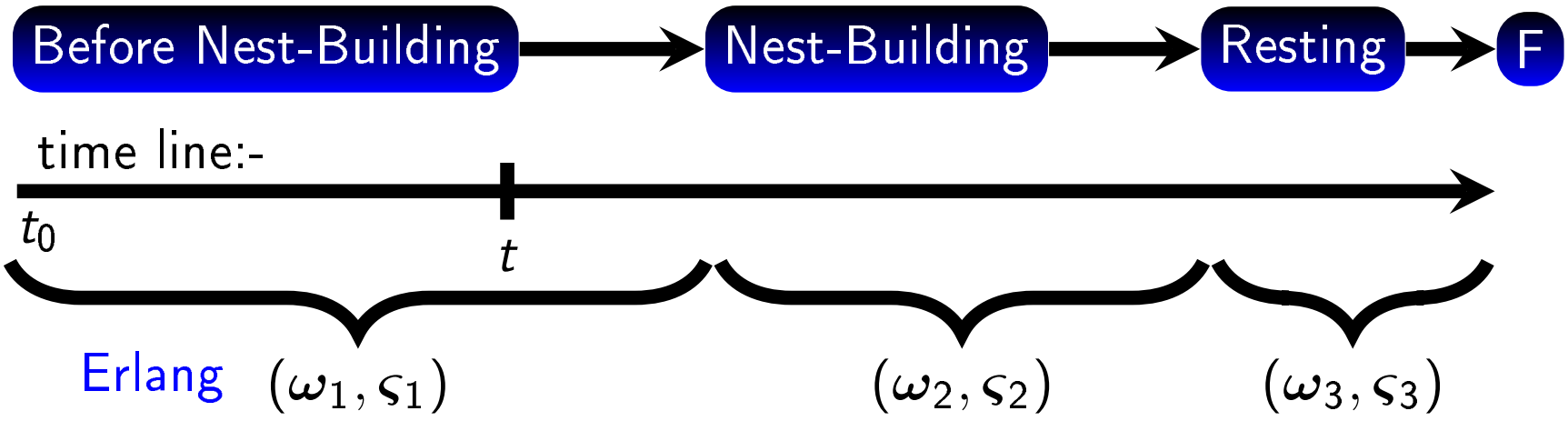

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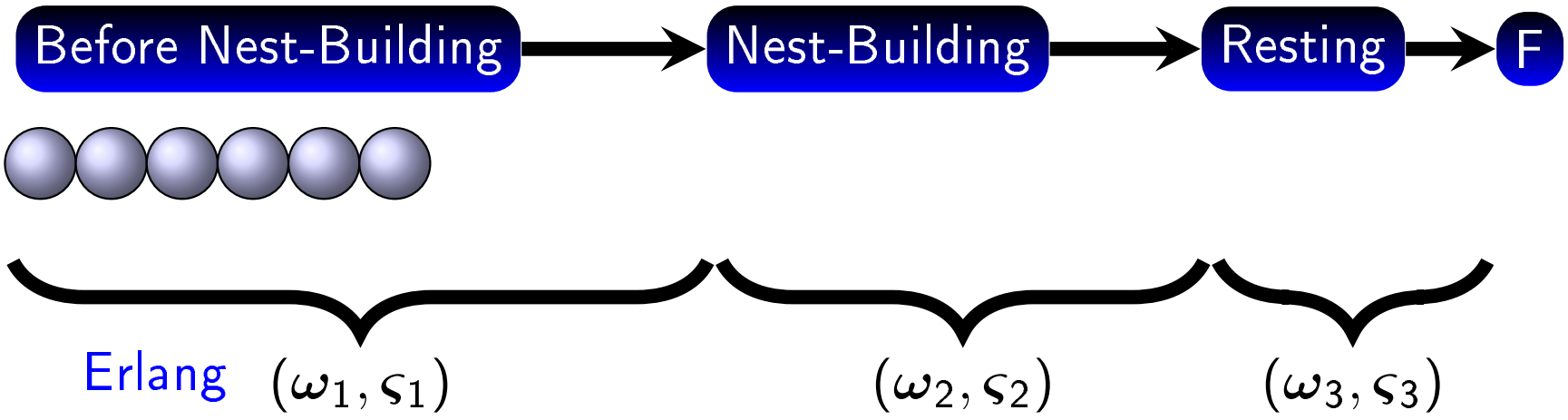

States into smaller divisions -> "Behavioural Phases"

'phases' reflect the time since mating

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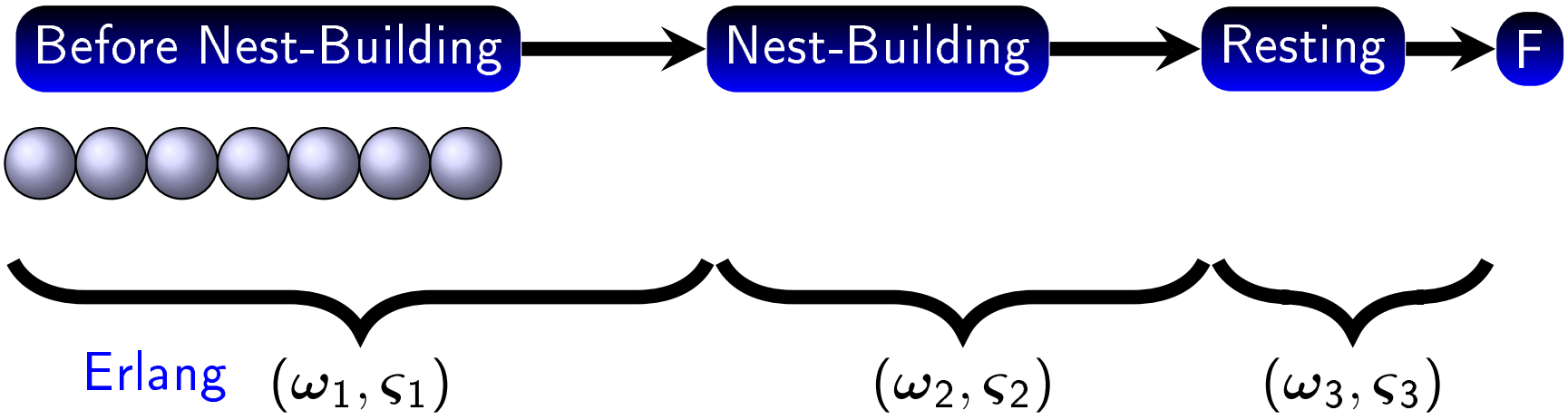

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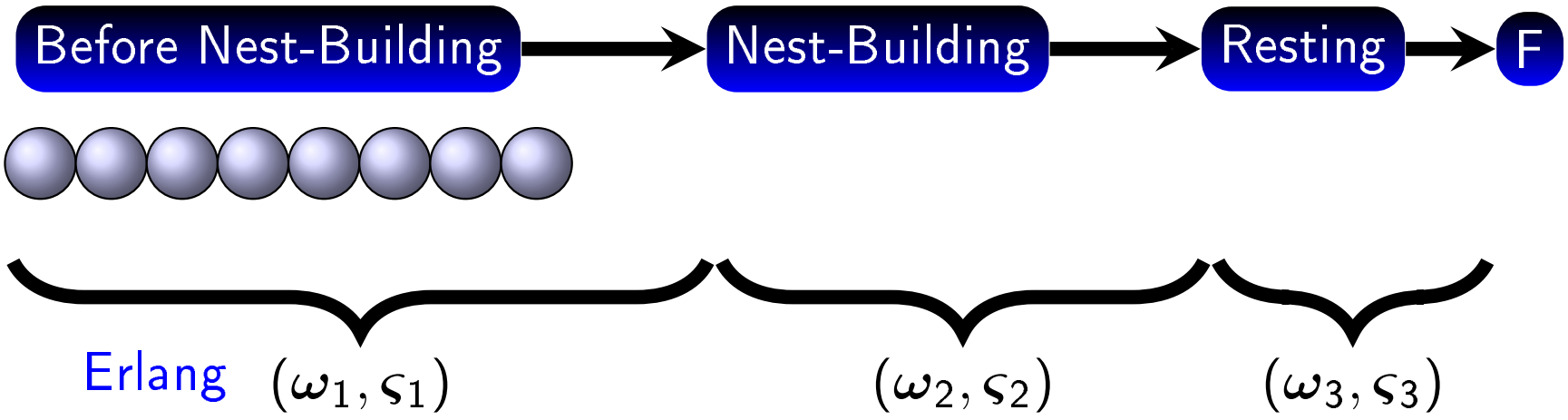

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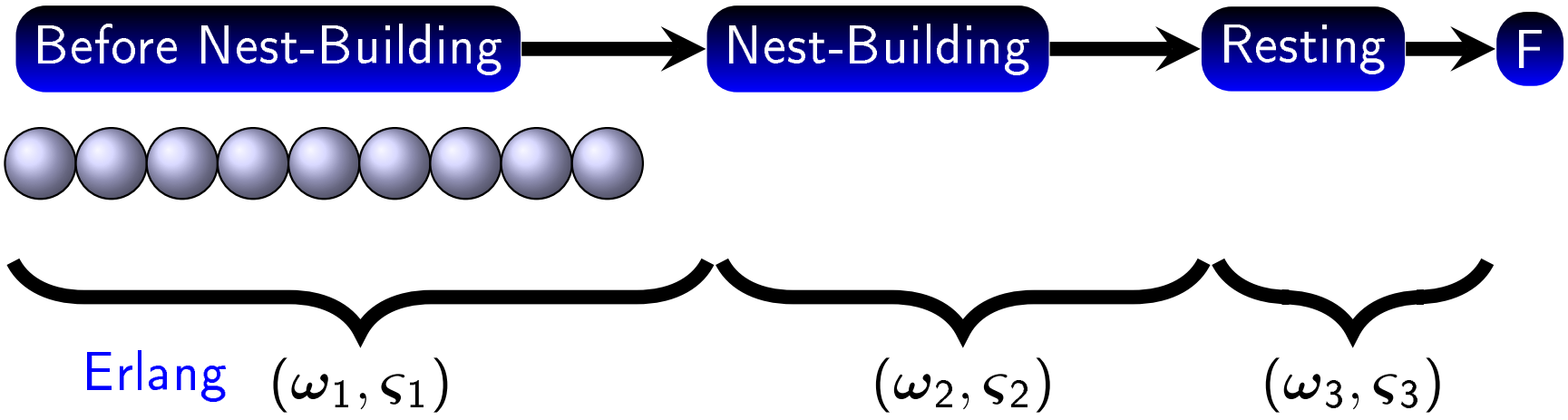

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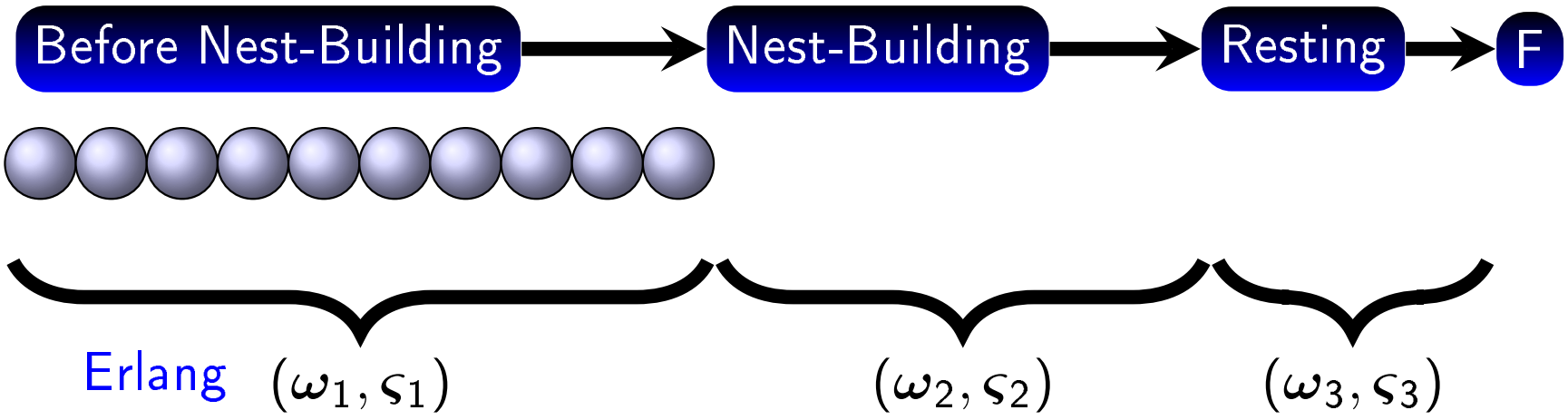

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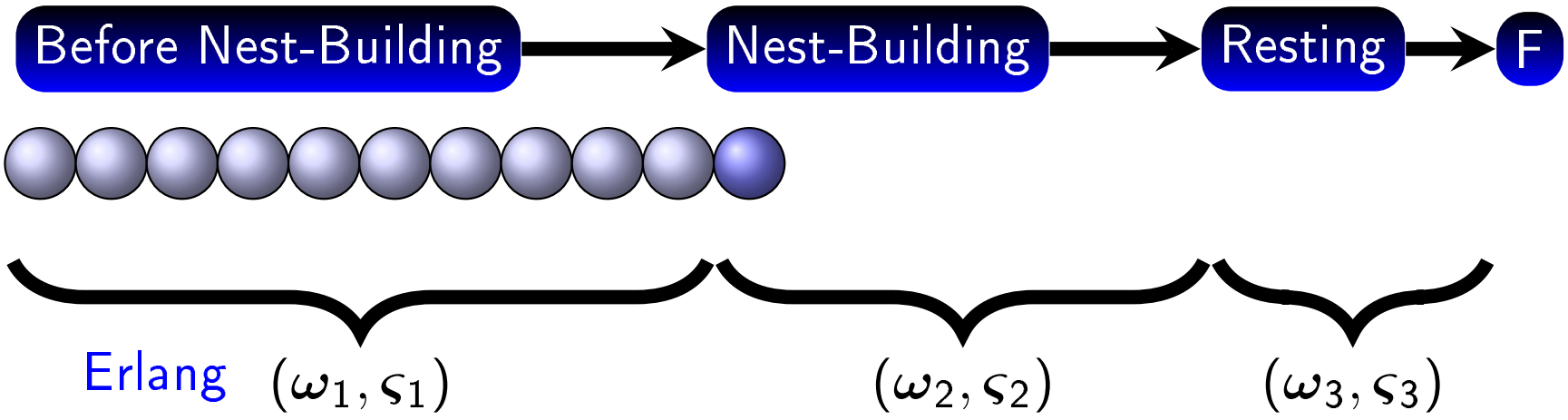

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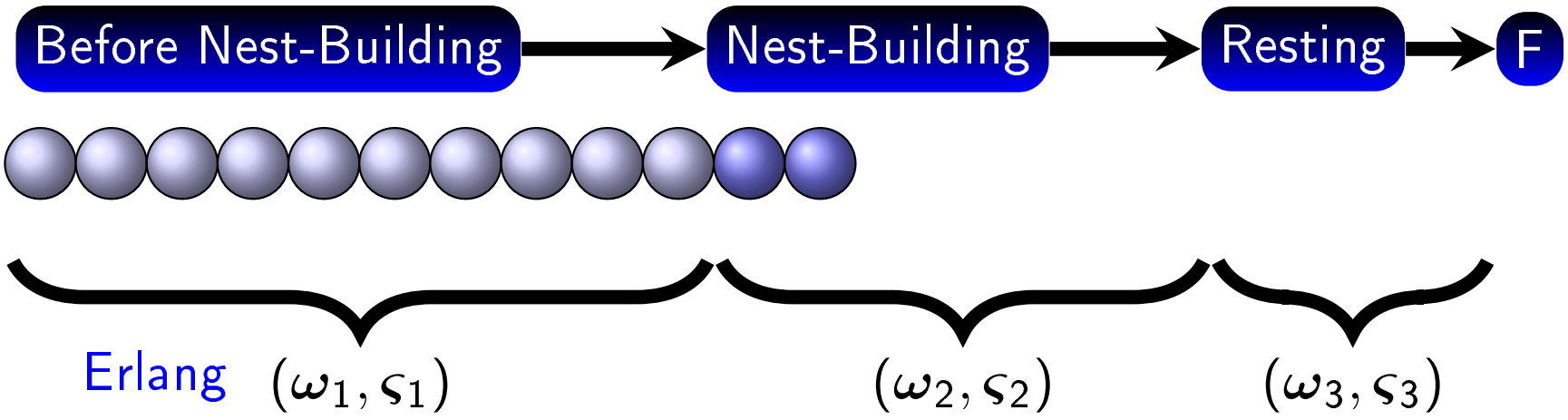

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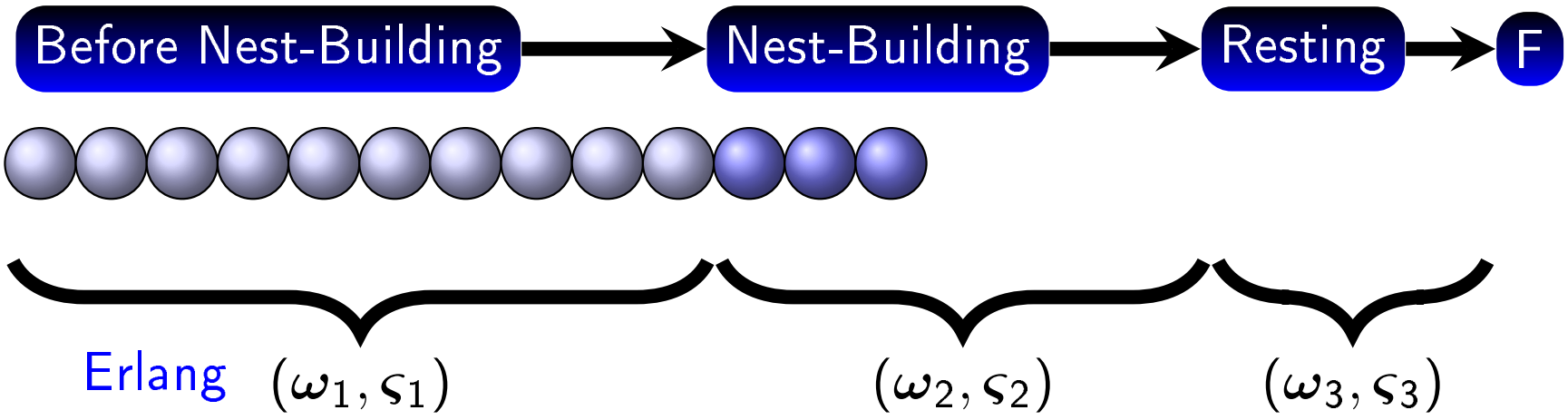

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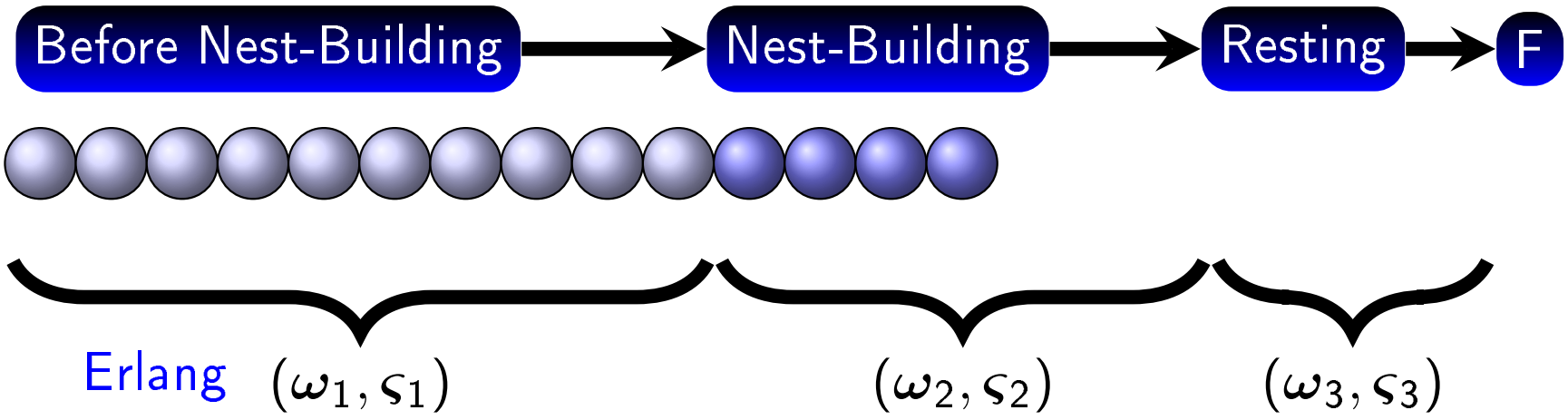

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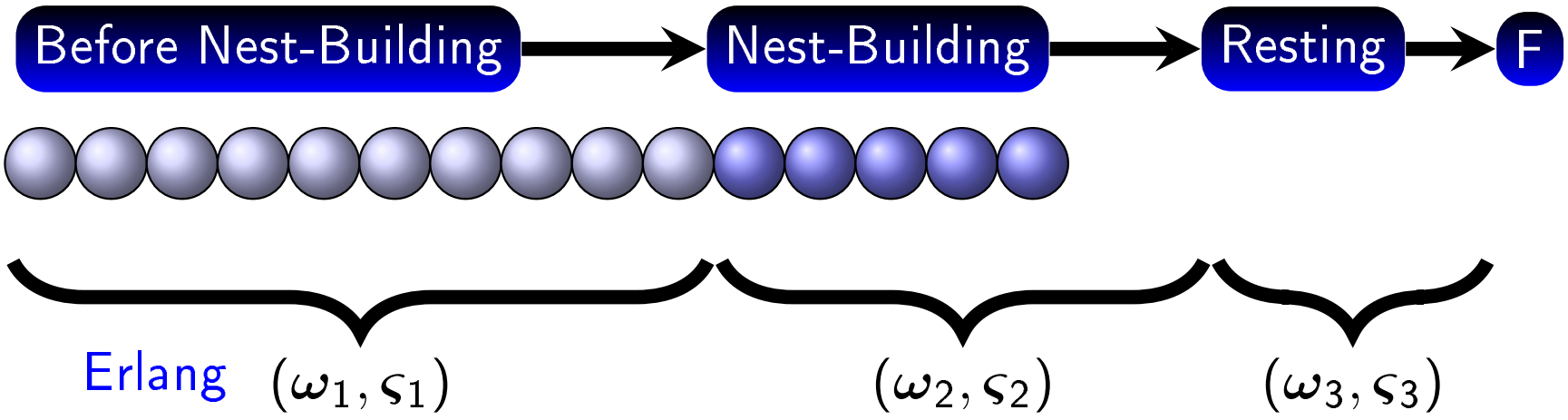

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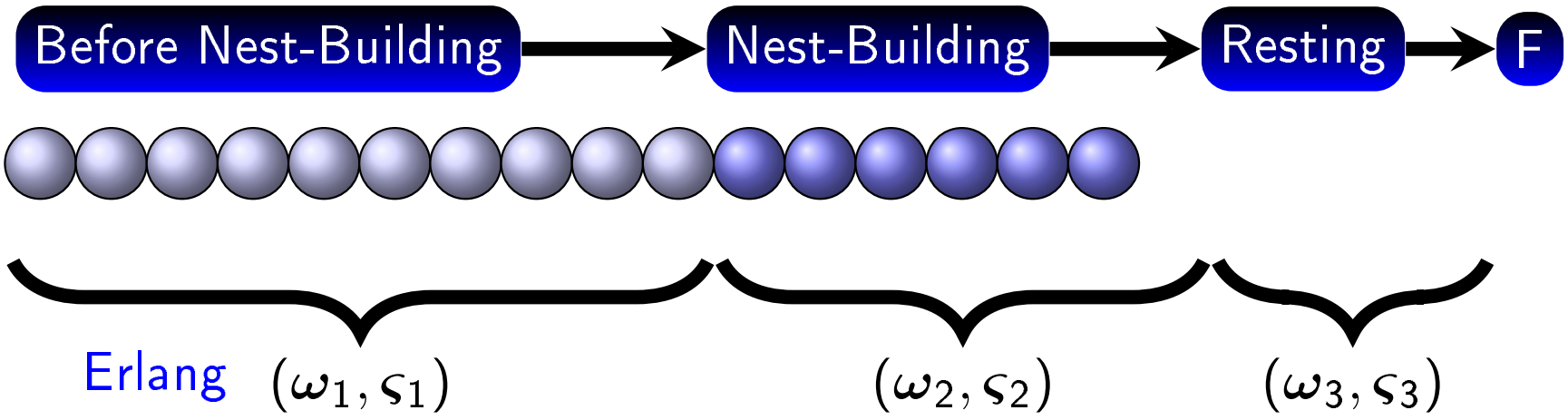

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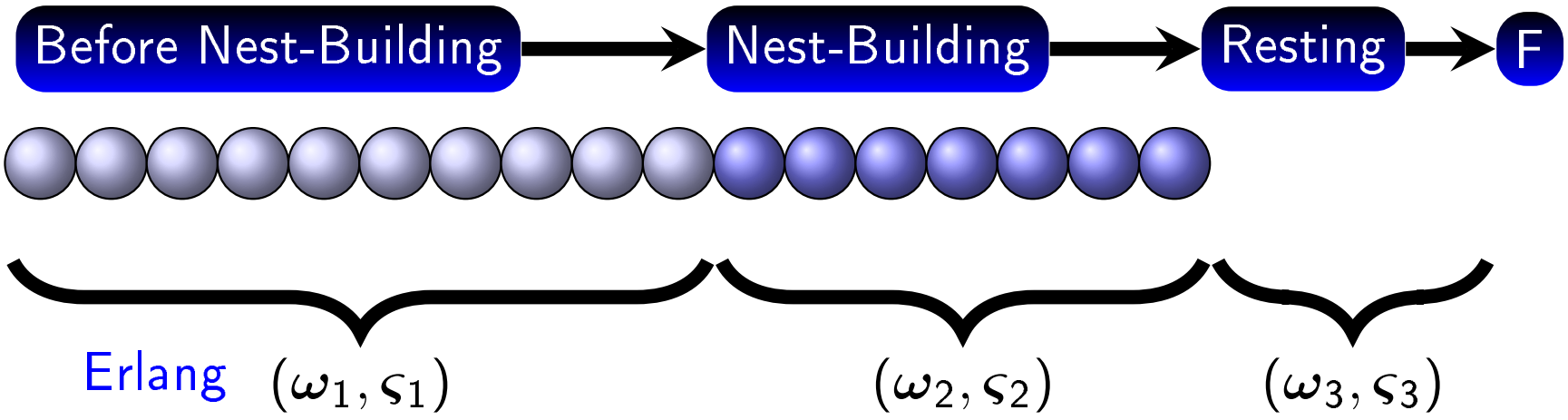

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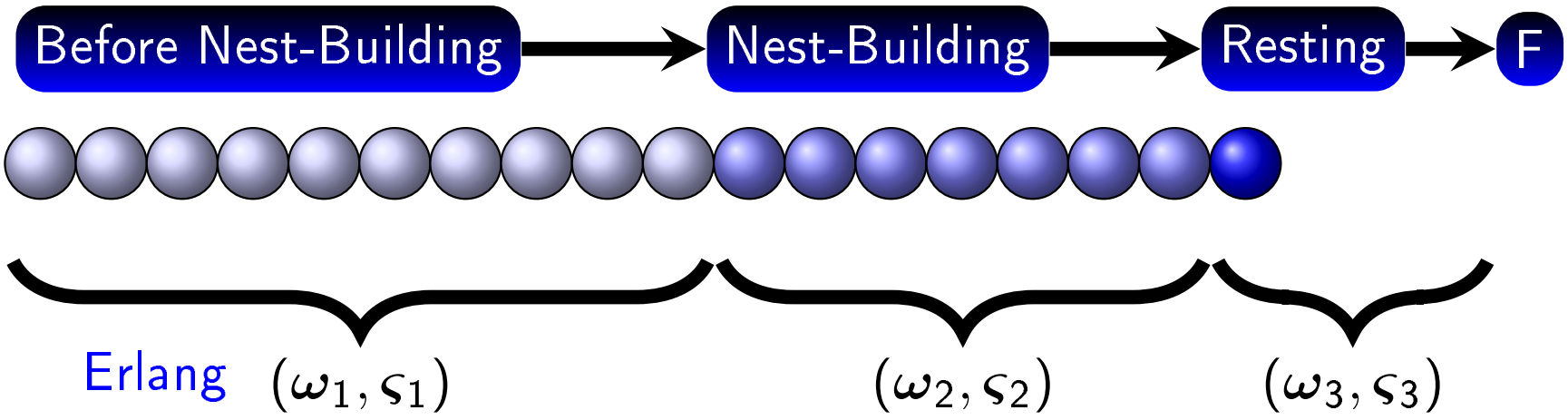

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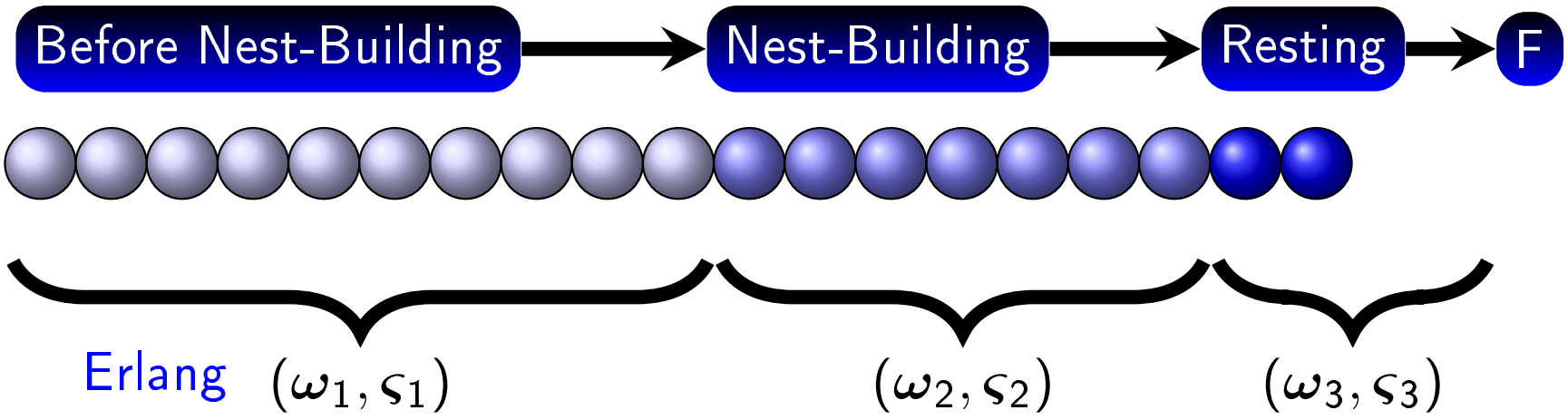

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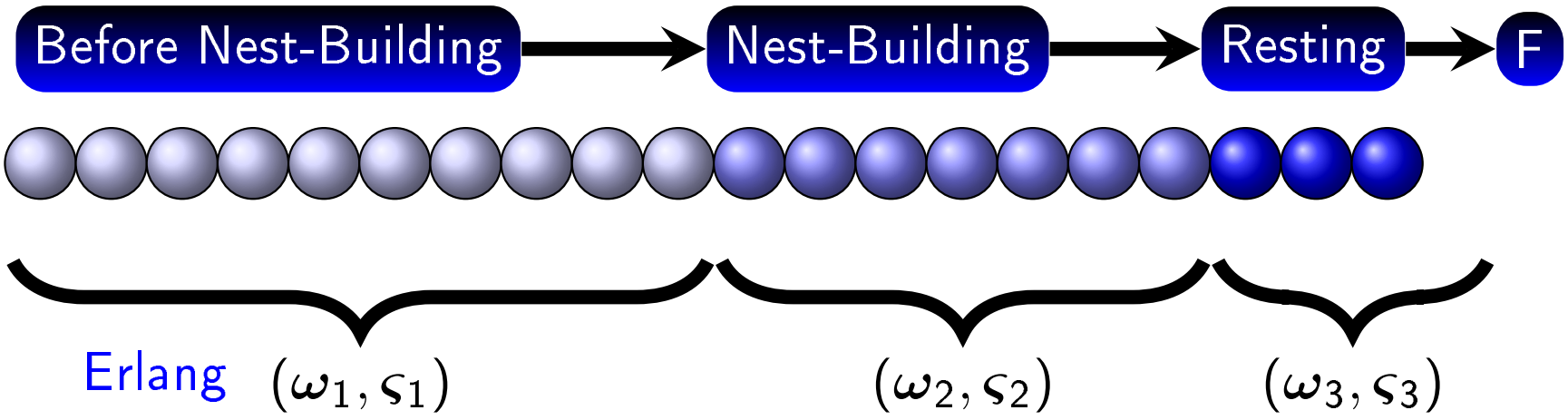

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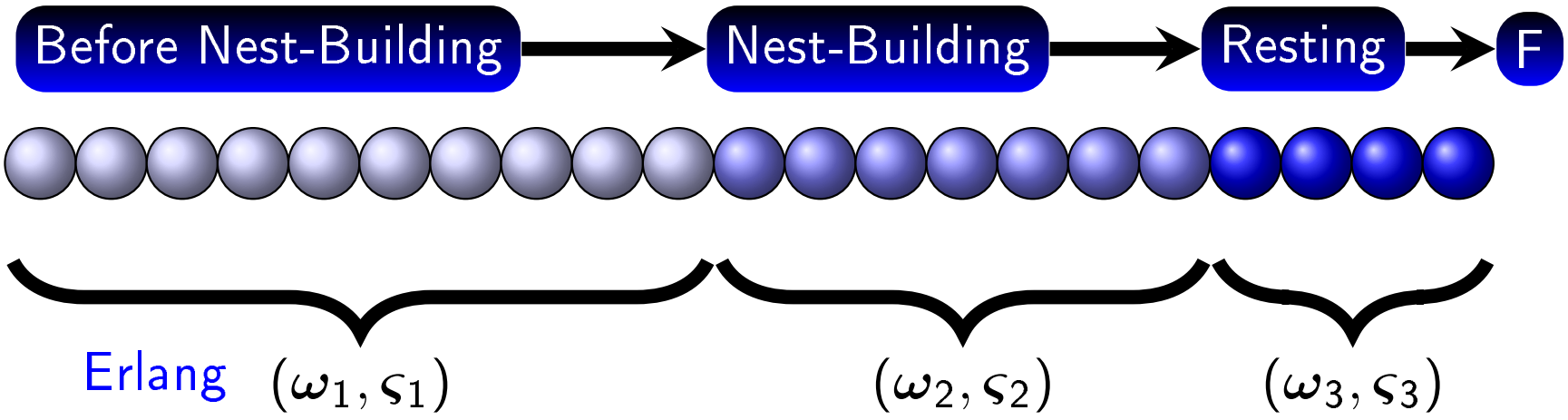

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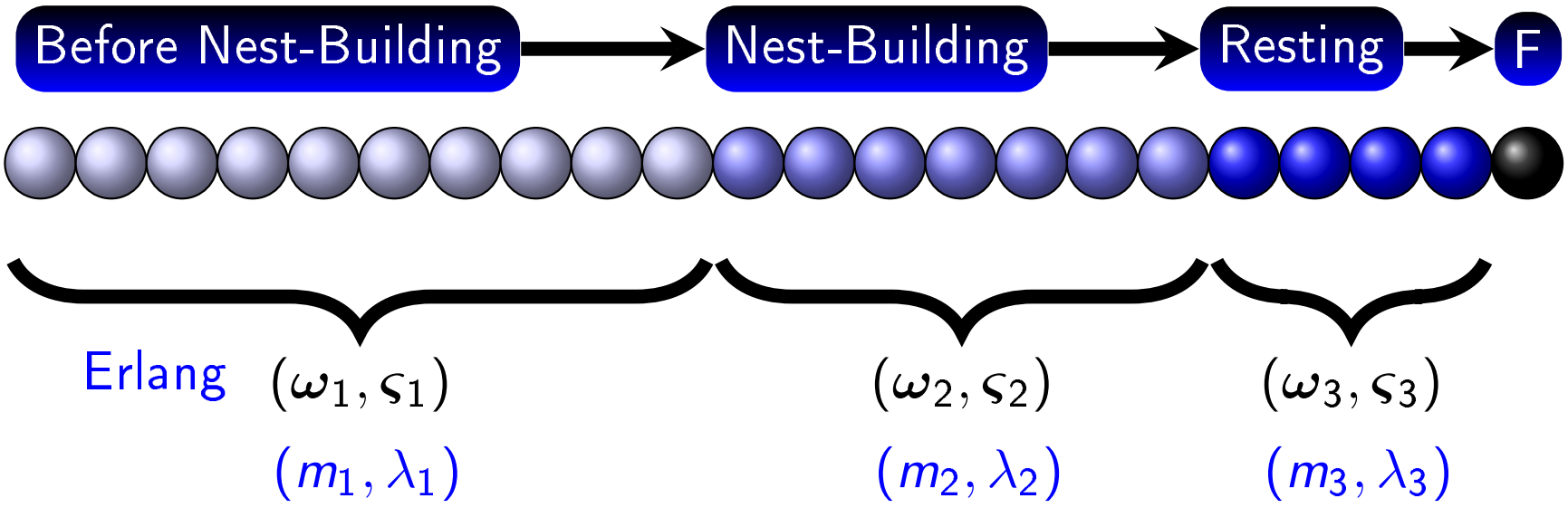

~~'semi'~~ Markov Process over phases

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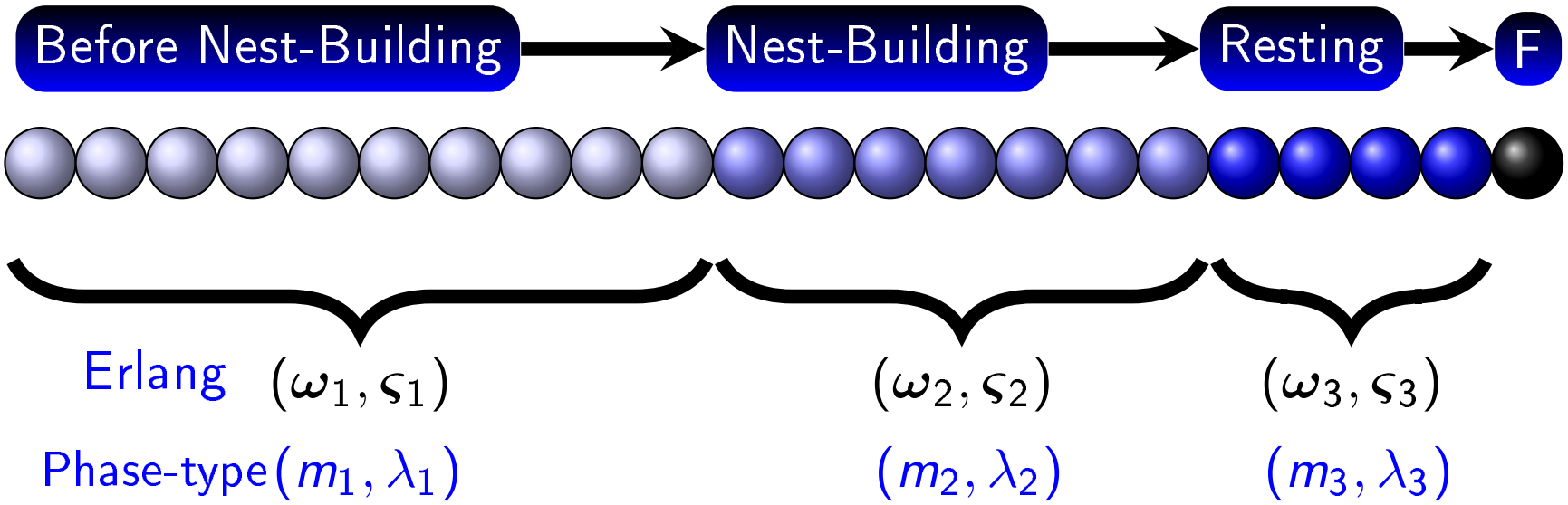
Farrowing process - continuous time



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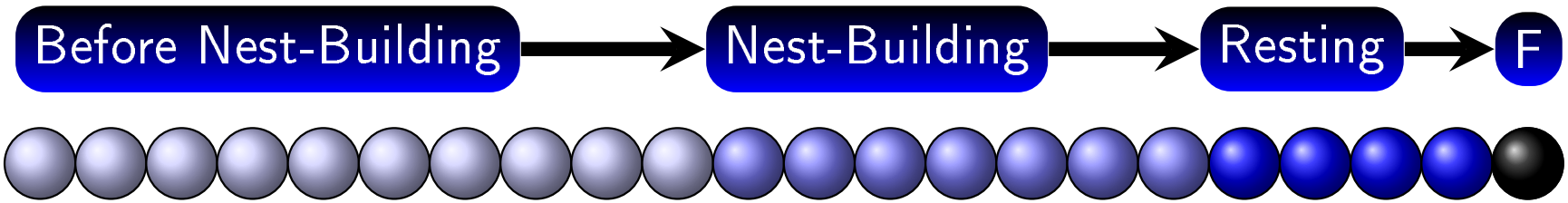
Convolution of three Phase-type distributions

Farrowing and Prediction Process

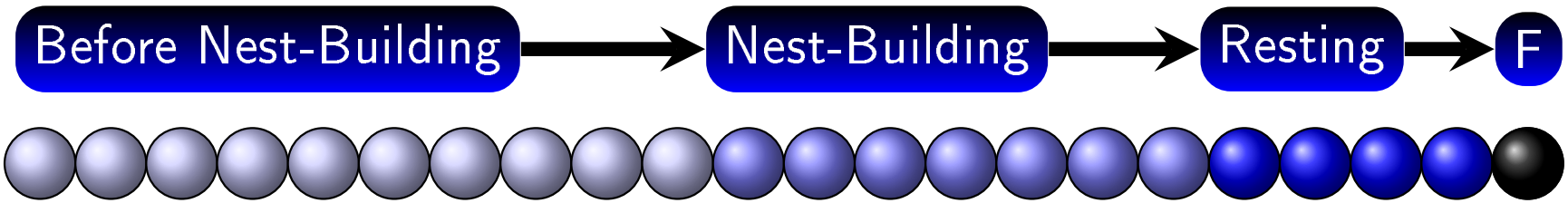
Farrowing process - continuous time



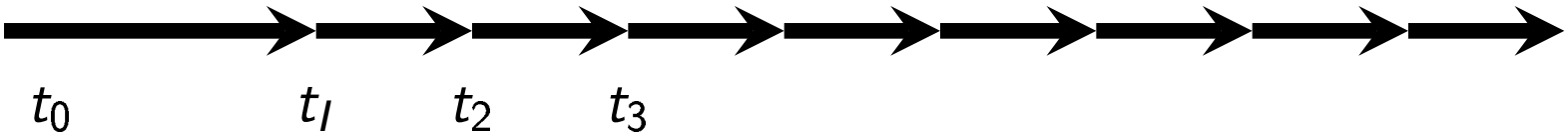
'Markov Model'

Farrowing and Prediction Process

Farrowing process - continuous time



Prediction process discrete time points



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Farrowing and Prediction Process

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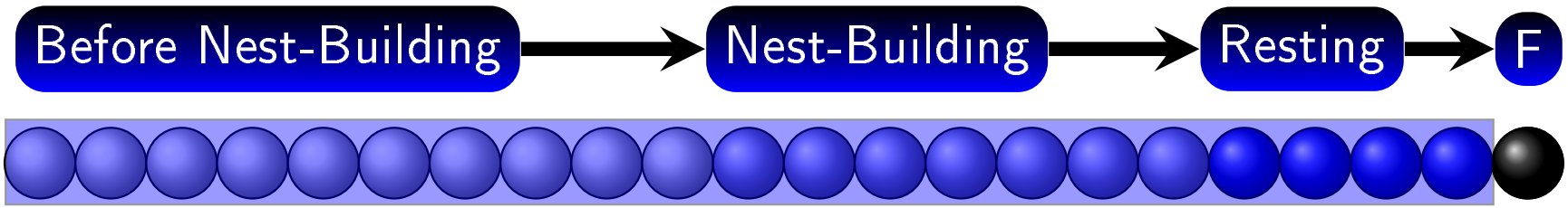

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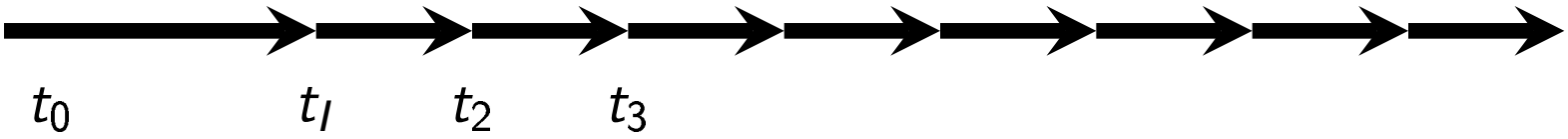
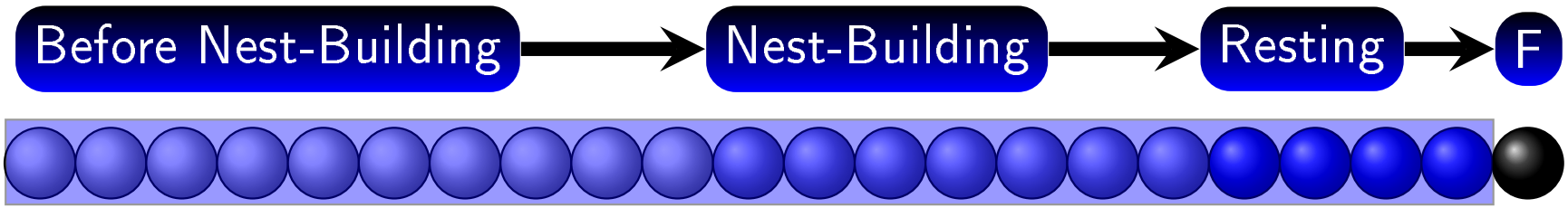


α_t : distribution of phases 'Hidden' + 'Markov Model'

T_t :*time to onset of farrowing* $\sim PH(\alpha_t, \mathbf{S})$

Farrowing and Prediction Process

Farrowing process - continuous time



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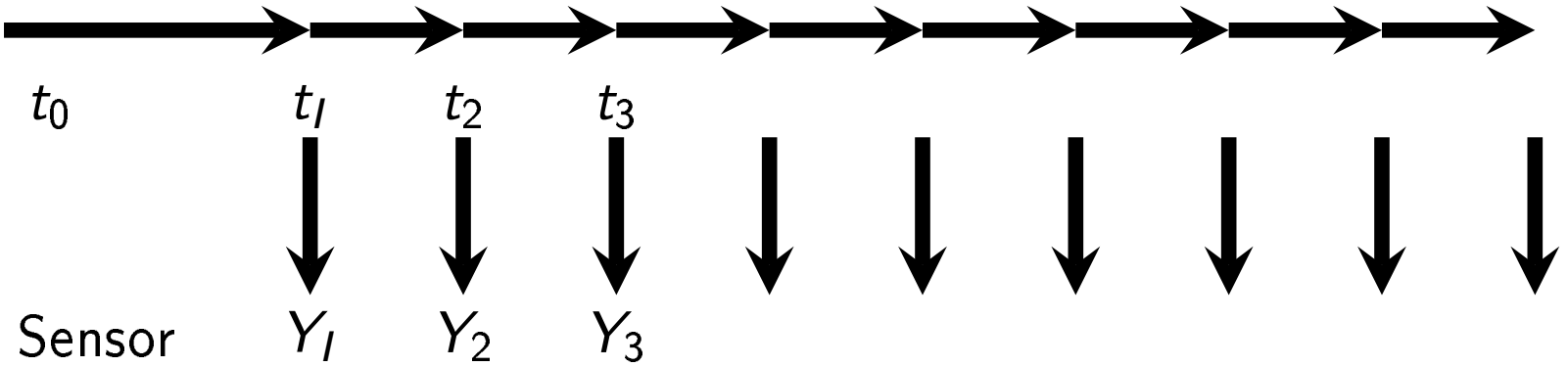

$\mathbf{Pr}(Y_t \mid \text{Phase}_t)$

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Farrowing and Prediction Process

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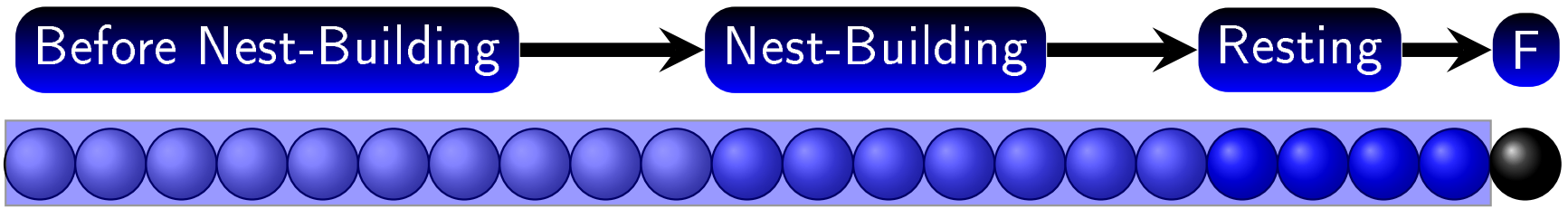

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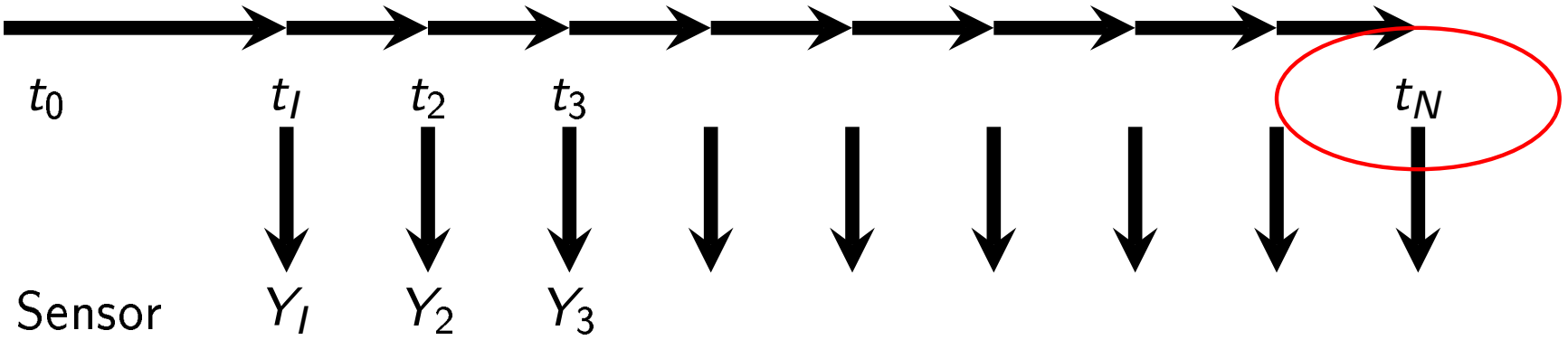

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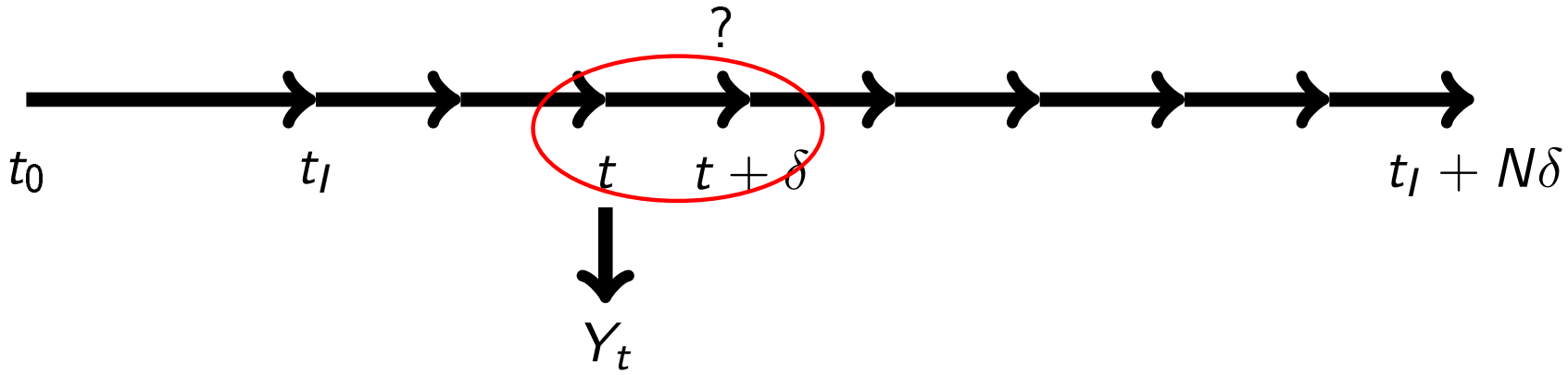
Prediction of Onset of Farrowing



$\alpha_{t+\delta}$: distribution of phases in the next prediction point

Prediction of $\alpha_{t+\delta}$

At each prediction point,

1. calculates $\alpha_{t+\delta}$ using time transition (Markov chain)
2. updates $\alpha_{t+\delta}$ using the sensor information

Prediction of Distribution of Phases $\boldsymbol{\alpha}_{t+\delta}$

Prediction of Onset of Farrowing

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$T_{t+\delta}$: *time to onset of farrowing* $\sim PH(\alpha_{t+\delta}, \mathbf{S})$

Statistical measures...

- Expected time to onset of farrowing

Prediction of Onset of Farrowing

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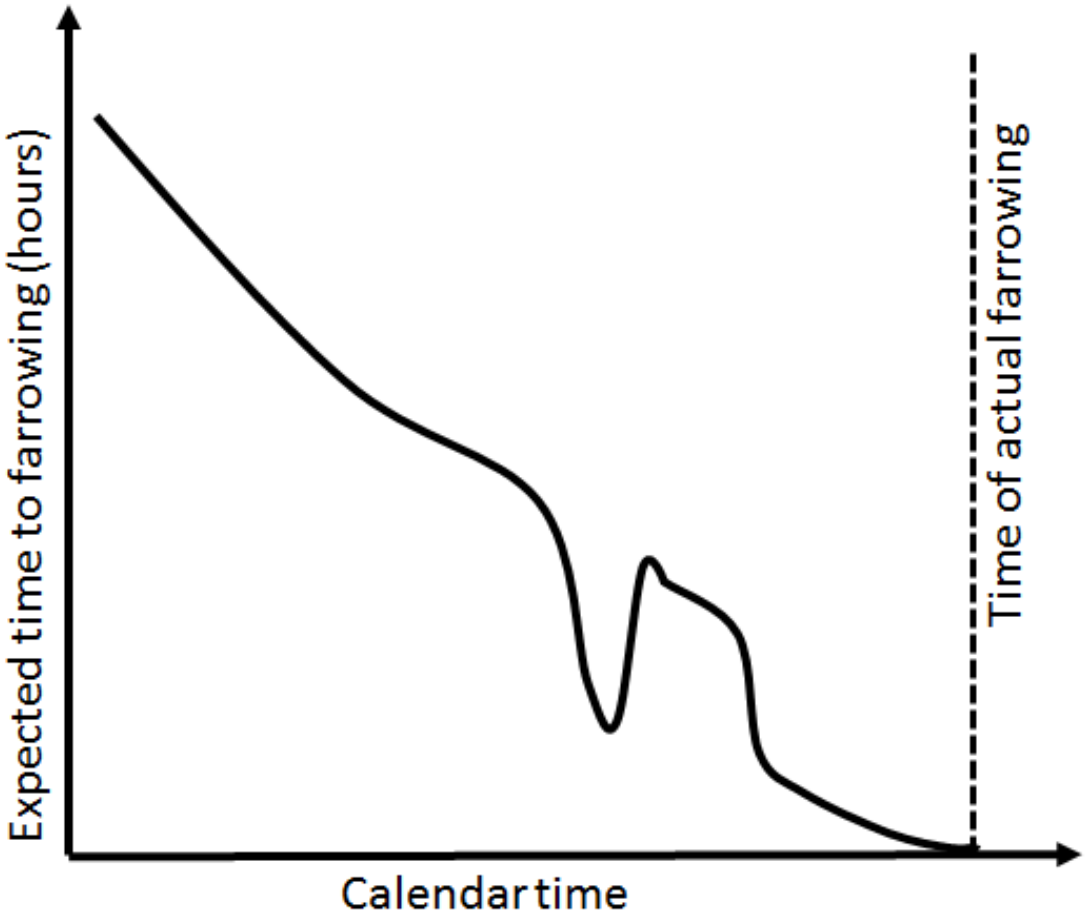
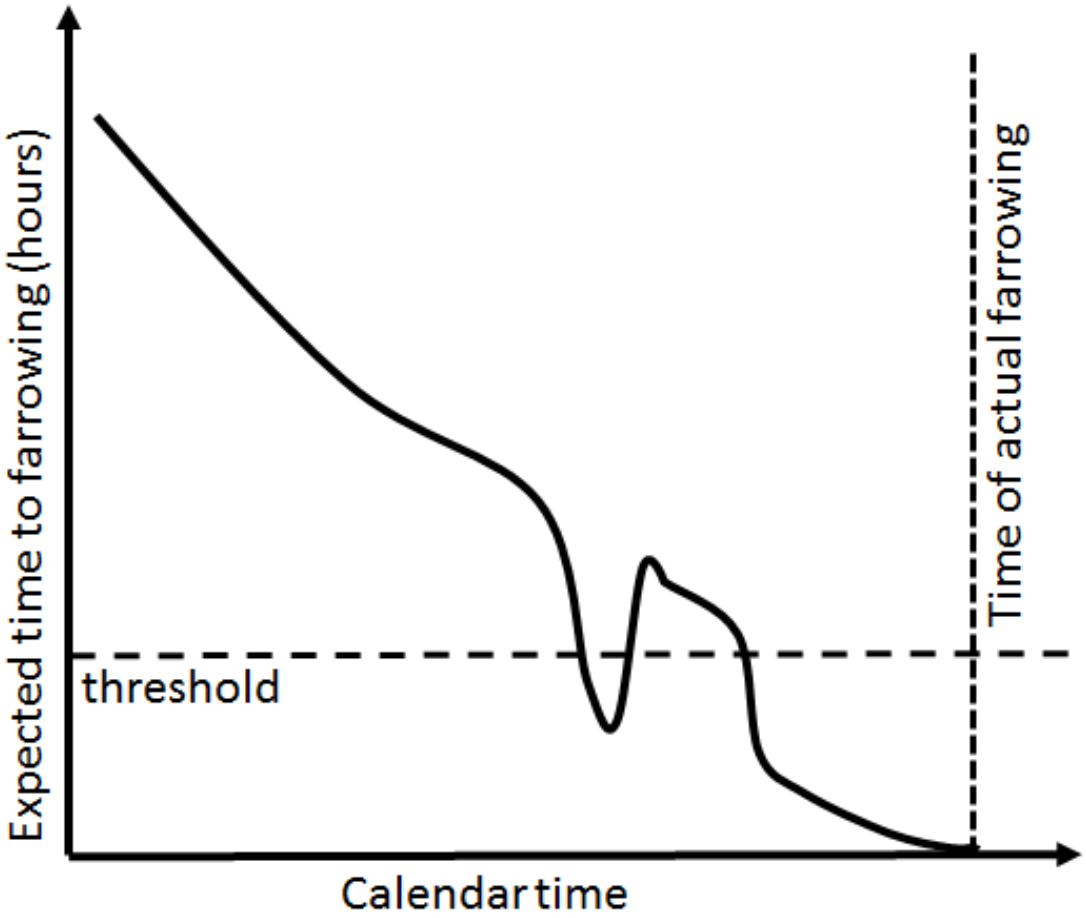
Statistical measures...

- Expected time to onset of farrowing
- Probability of onset of farrowing in 12 hours

Validating the Prediction - how???

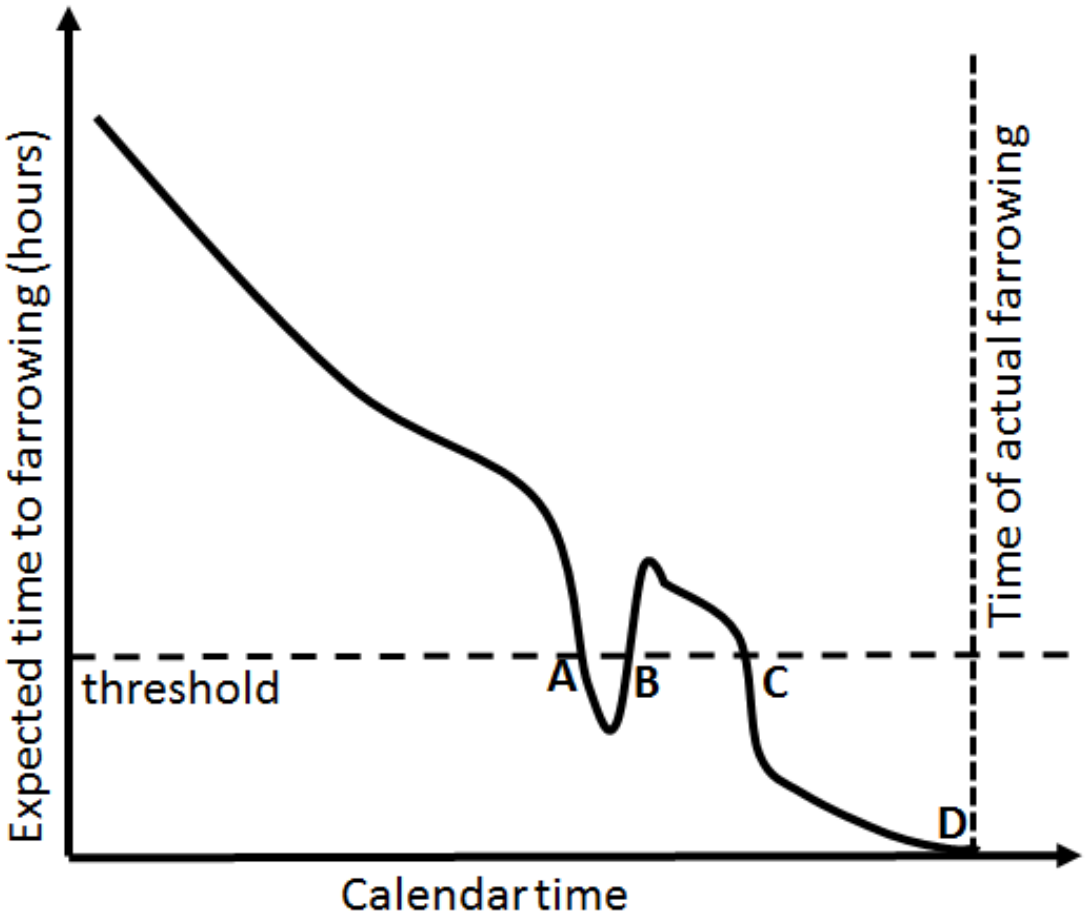


Validating the Prediction - how???



Online Prediction Curve - an example

Warning periods - success Vs failure



Example of False-warning Period

Validating the Prediction Algorithm

Sensor	Sample size	True Warnings %	Warning Dur. (hours) Mean	SD	Error (hours)
Water	38	21	11.7	2.2	3.4
Video	55	98	14.4	12.5	1.6
Water-Video	35	97	11.5	4.6	0.7

*threshold set at 12 hours

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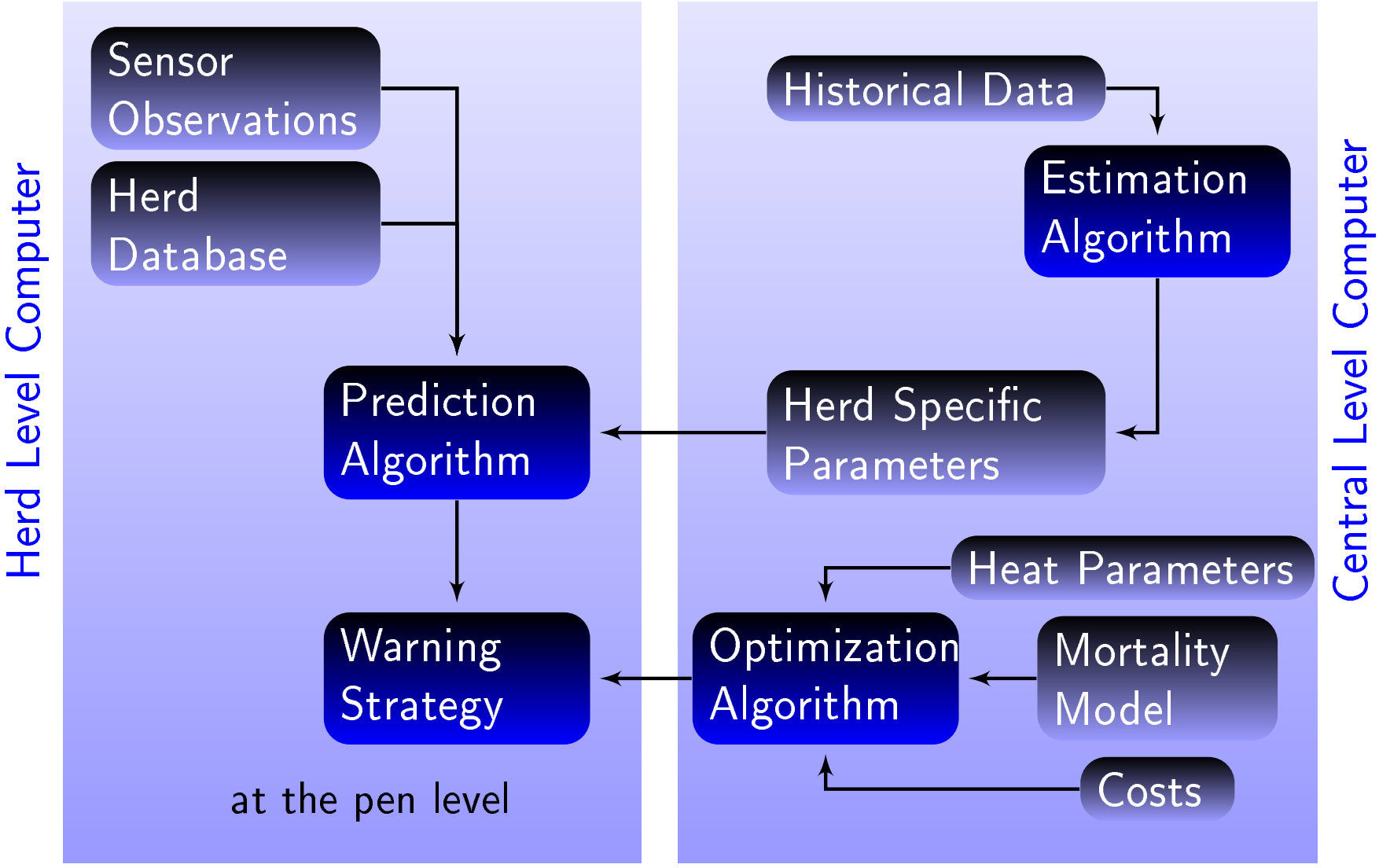

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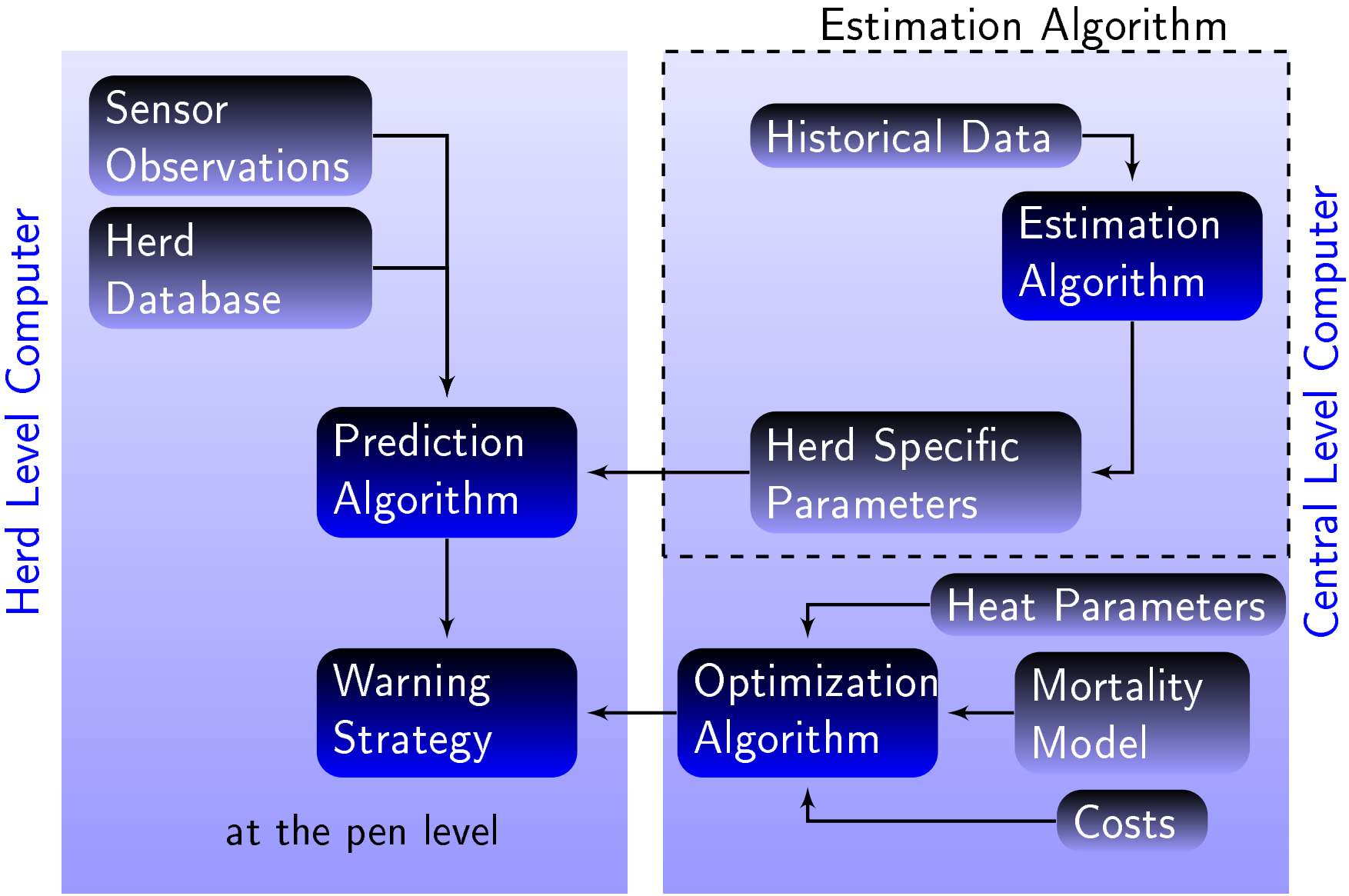

Estimation of HPMM Parameters

by maximizing the likelihood function

Estimation of HPMM Parameters

by maximizing the likelihood function
Stochastic Expectation-Maximization algorithm (SEM algorithm)
-iterative method

- Uses time of mating and farrowing information in addition to sensor information
- Phases are allocated by weighted sampling - Stochastic

Estimated Sojourn time distribution

Behavioural State	Duration (hours) Mean	SD	Number of Phases	Rate (per hour)
Before Nest-Building	751.20*	29.58	645	0.86
Nest-Building	17.02	0.80	458	26.91
Resting	0.53	0.22	6	11.40
Gestation period, days	117	1.2	1109	-

*in addition to 85 days

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Conditional Distribution of Sensor Observation

Challenges with conditional model

- changing pattern with calender time - Behavioural Phases/States

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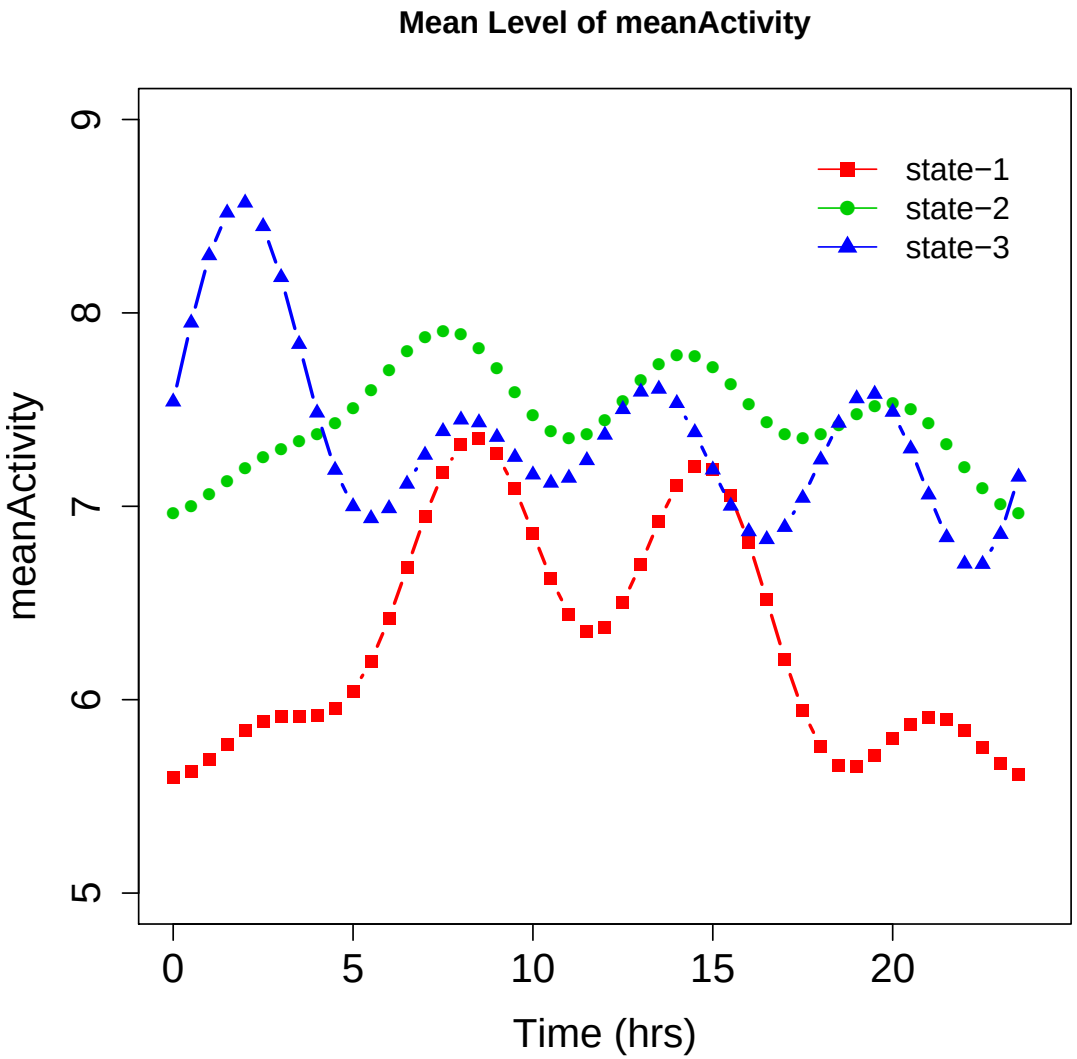
- dependency on the phases

Conditional Distribution of Sensor Observation

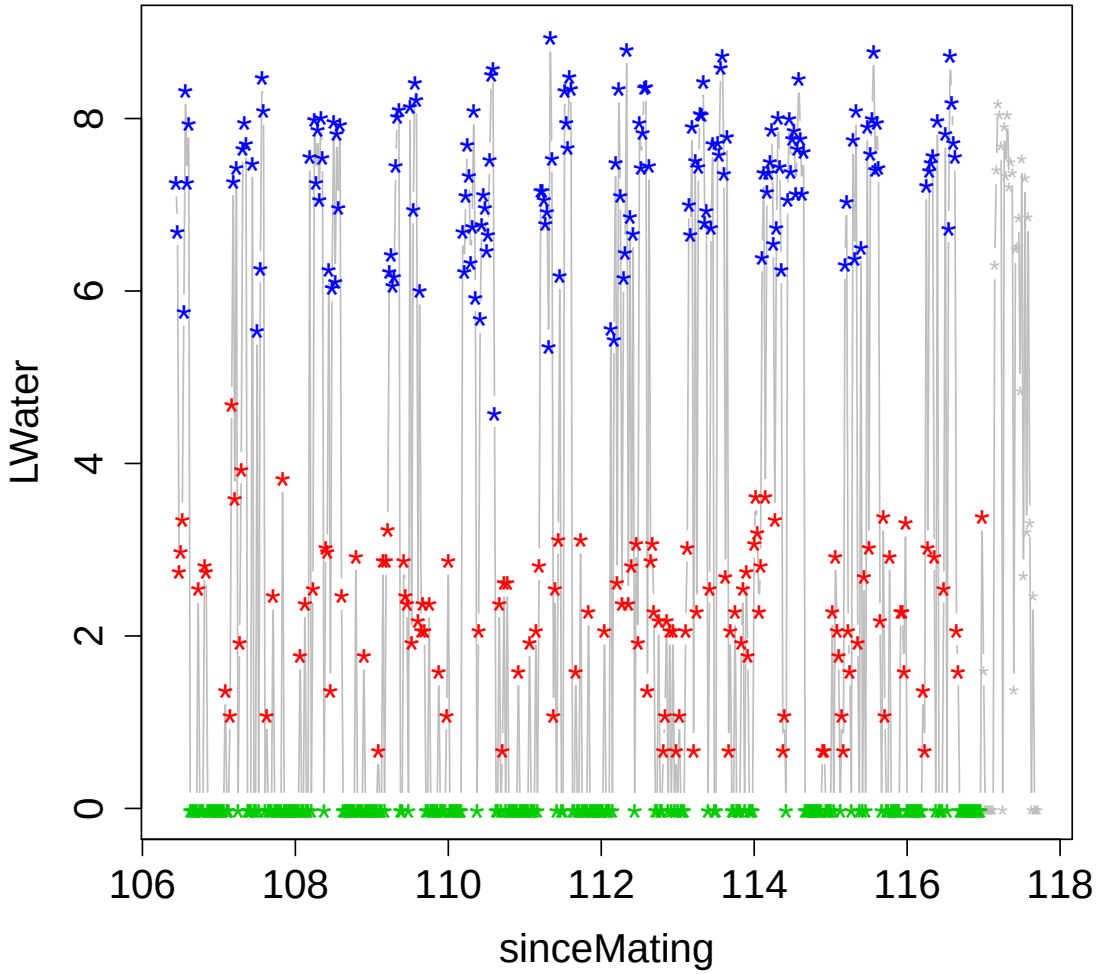
meanActivity - sdActivity - grid activity

- $\mathbf{Pr}(Y_t \mid \mathcal{S}_i) \sim \mathcal{N}(\mu_i^{(Y)}, \sigma_i^{2(Y)})_\zeta$
- Simple linear model
- sine-cosine functions - harmonic variables

Conditional Distribution of Sensor Observations



Pattern of Water Consumption



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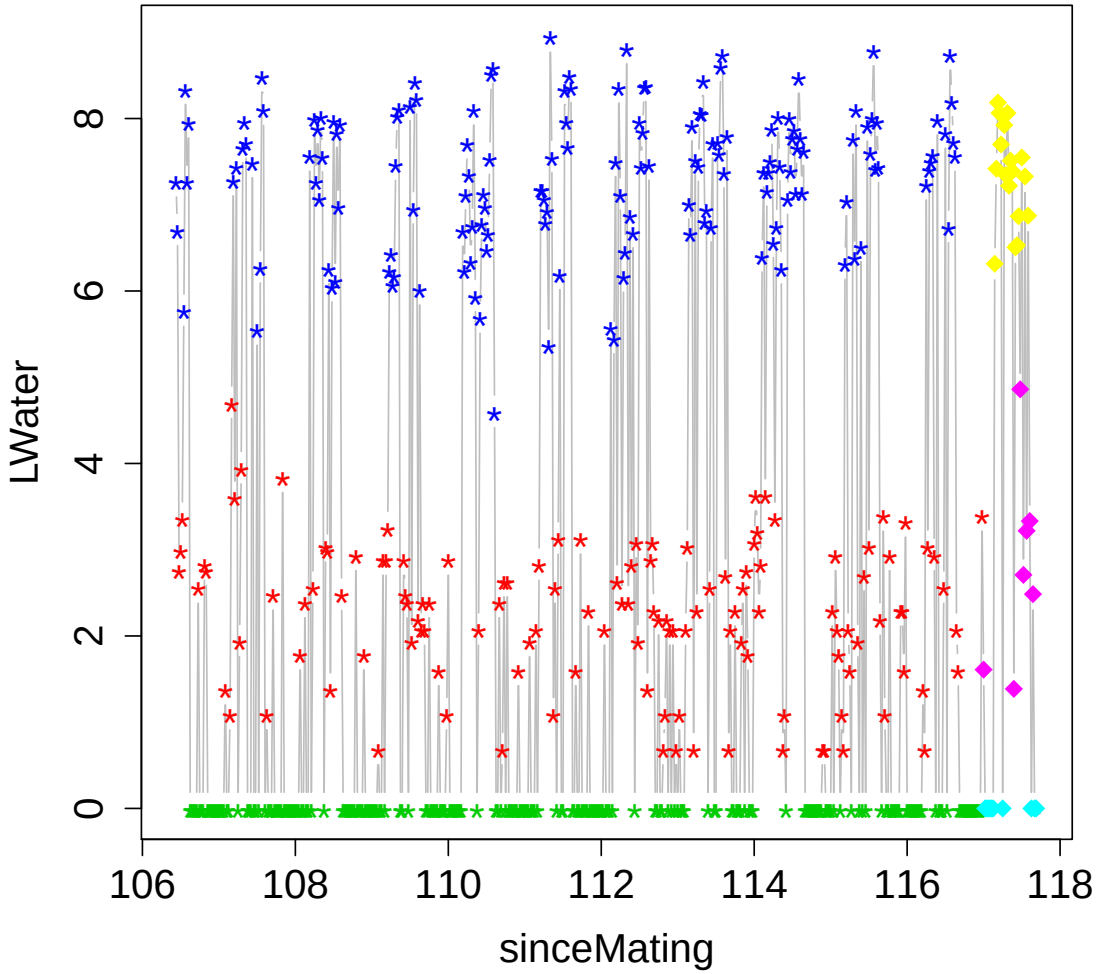
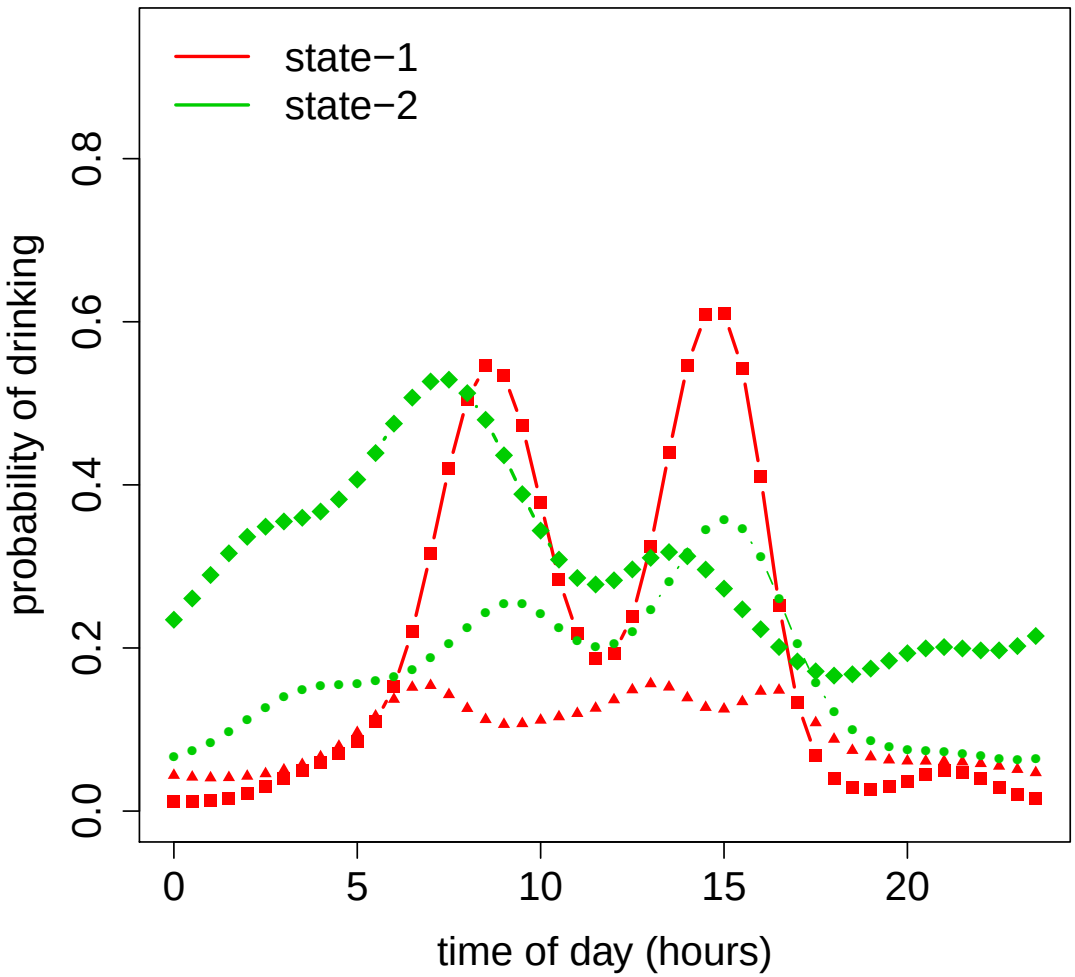


Probability of Water Consumption

at given time of day and state



Estimation of HPMM Parameters

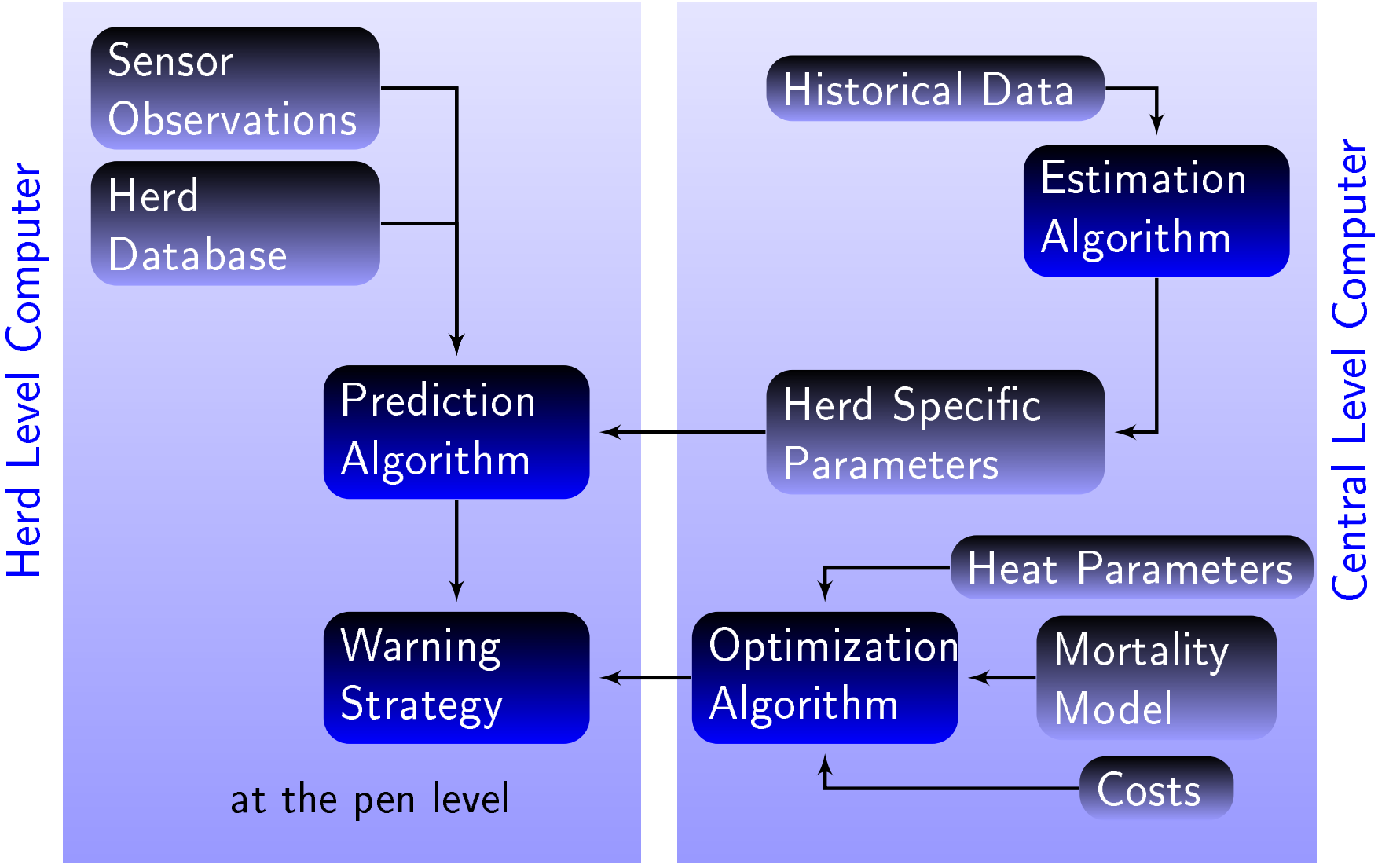
Challenges with conditional model

- changing pattern with calender time - Behavioural Phases/States ✓
- diurnal rhythm conditioned on the Phase/State ✓
- model selection ✓
- dependency of the variables ?
- dependency on the phases ?

Conclusion

- Duration of the *Nest-Building* state is similar to other studies
- Computational time - 26mins per iteration

Overview of the Study



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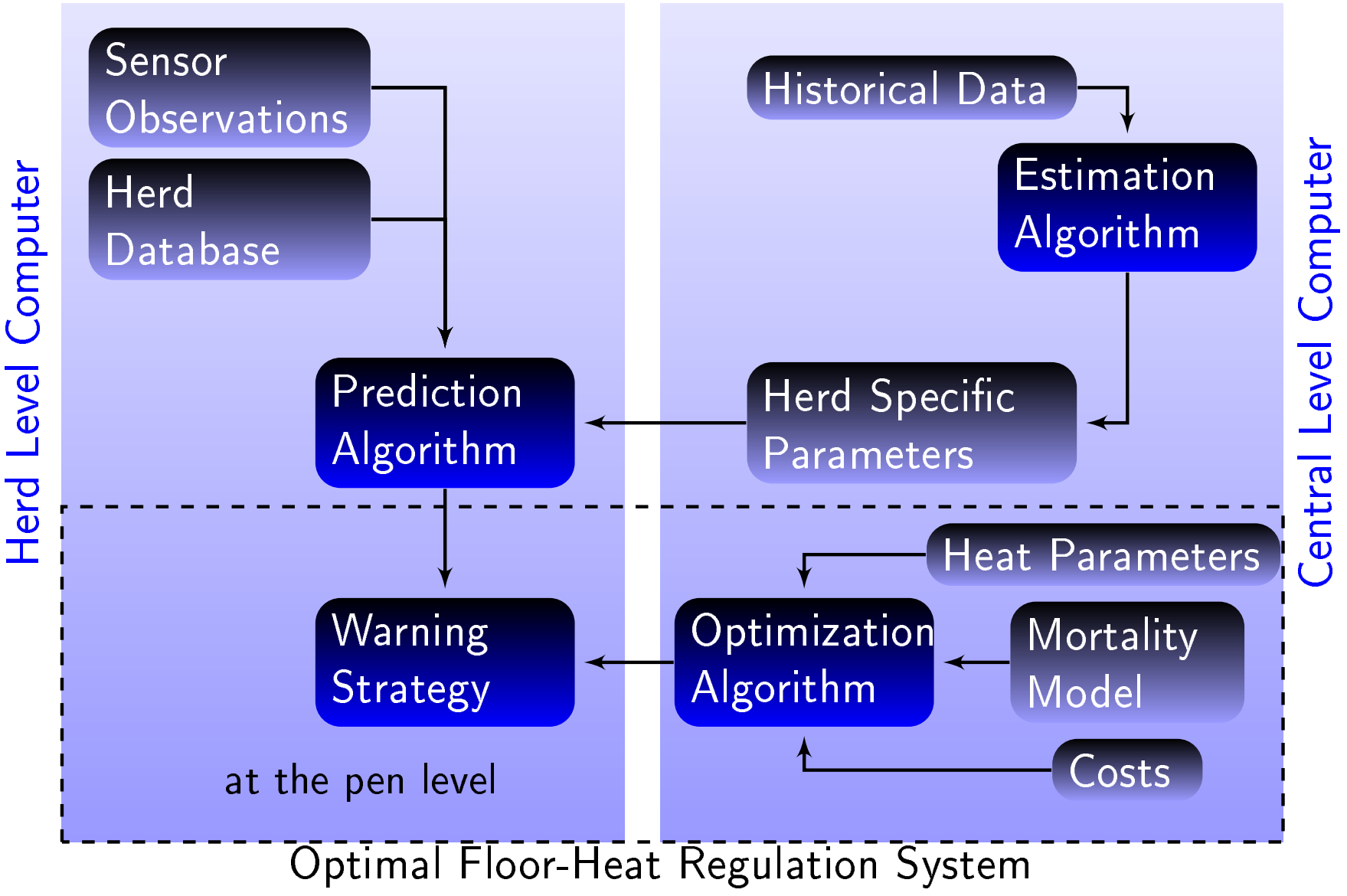

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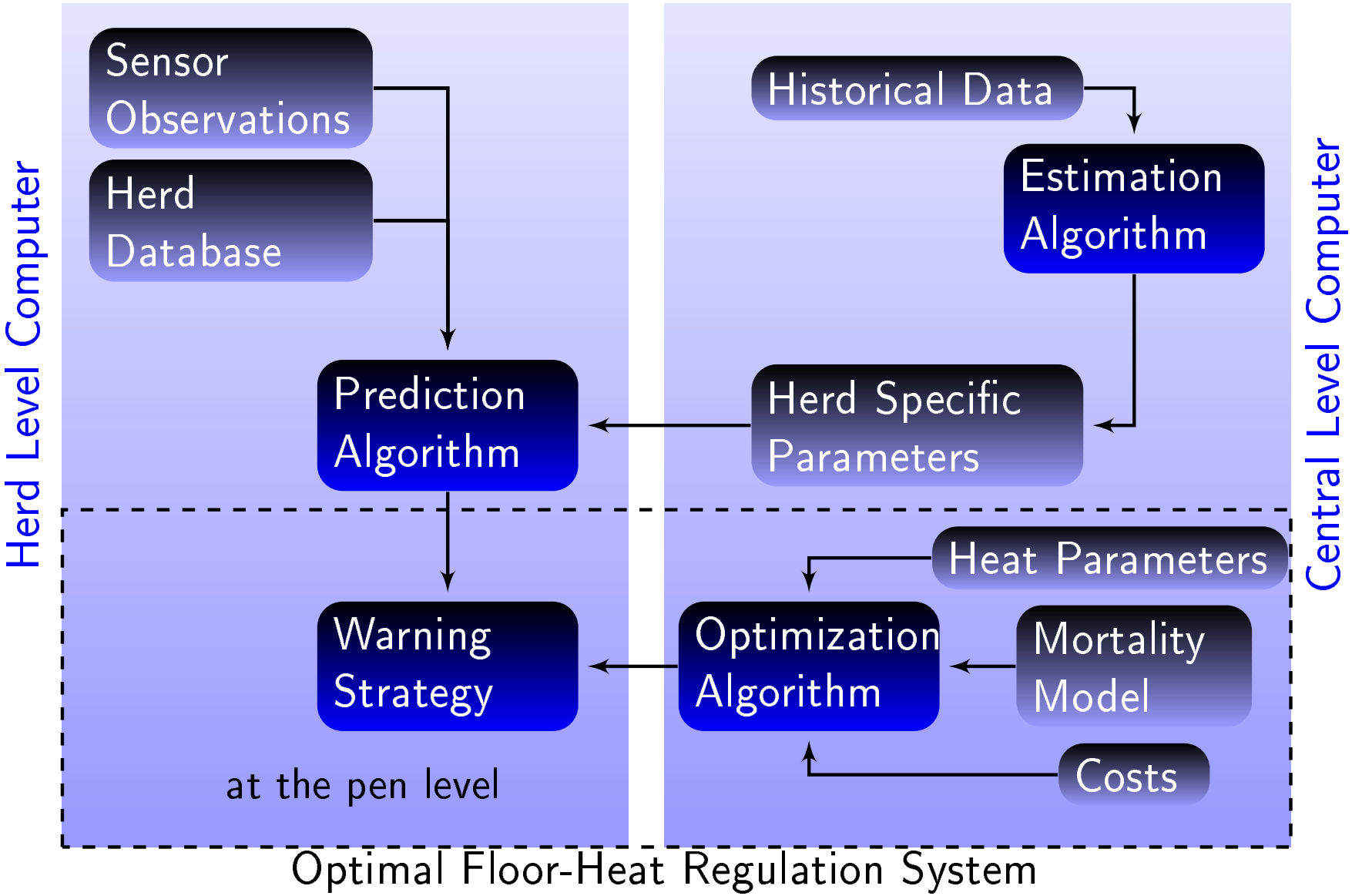
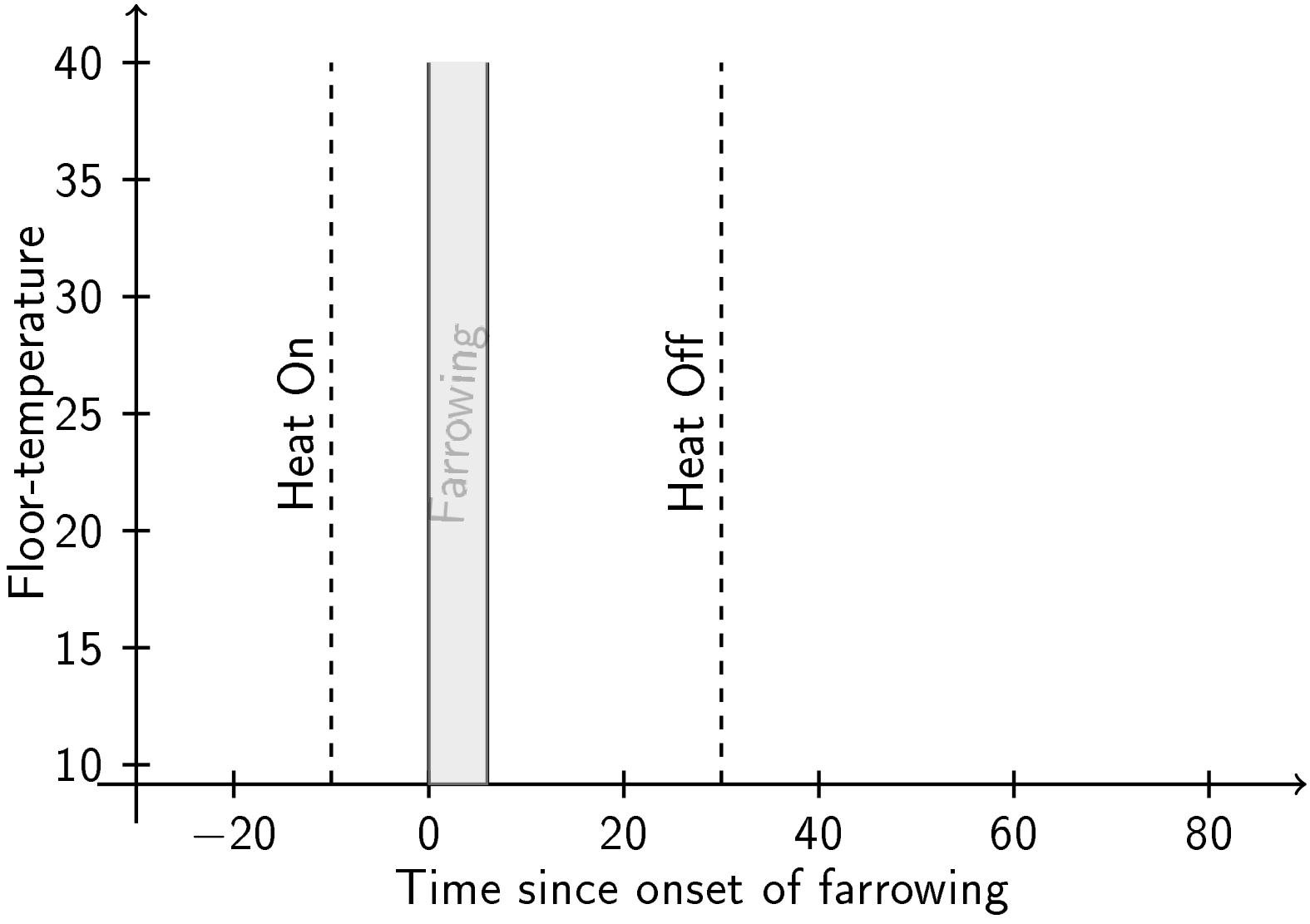


Floor-heat Regulation on Pen Level



Malmkvist et. al. (2006)→ survival of one extra piglet per litter

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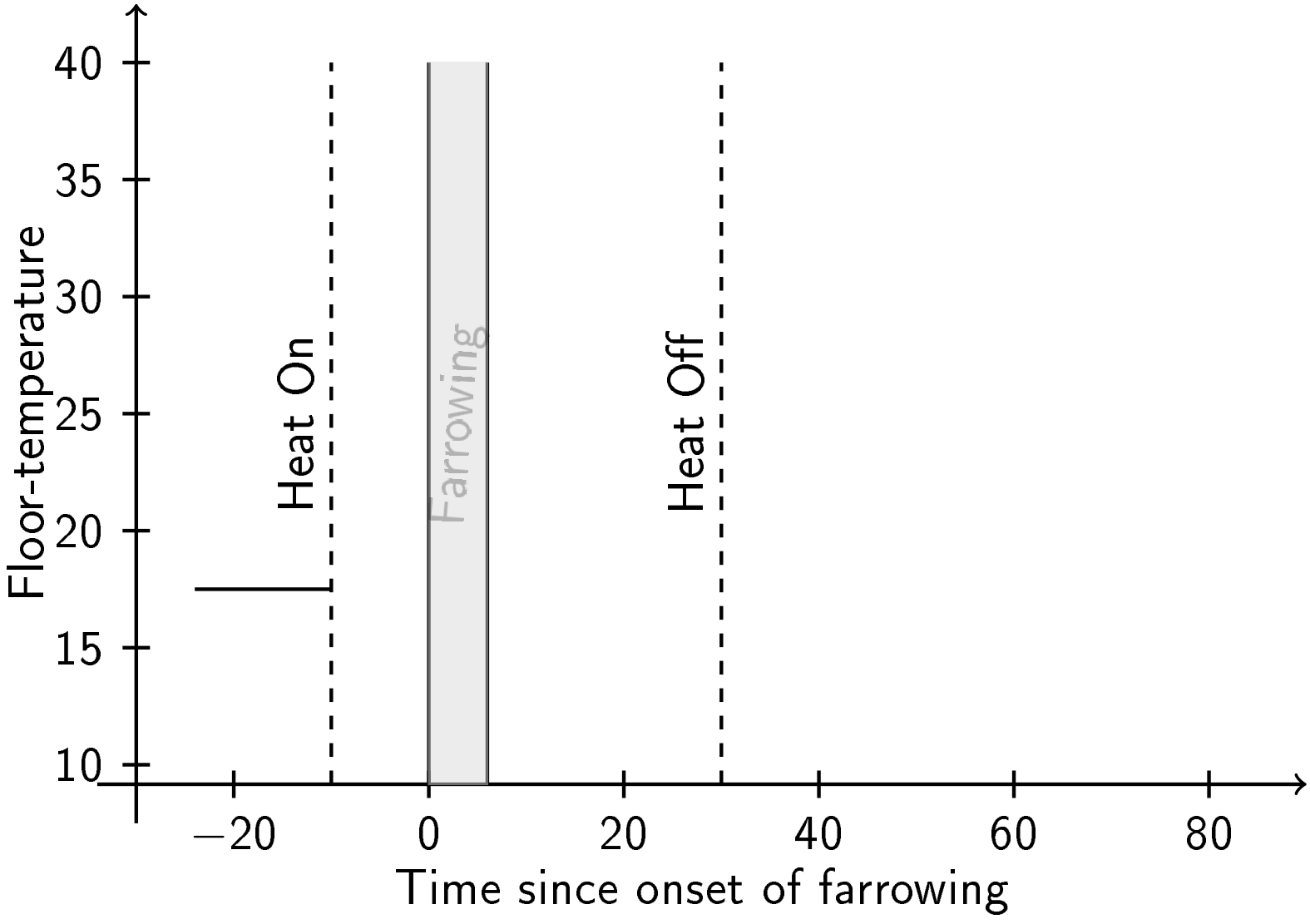

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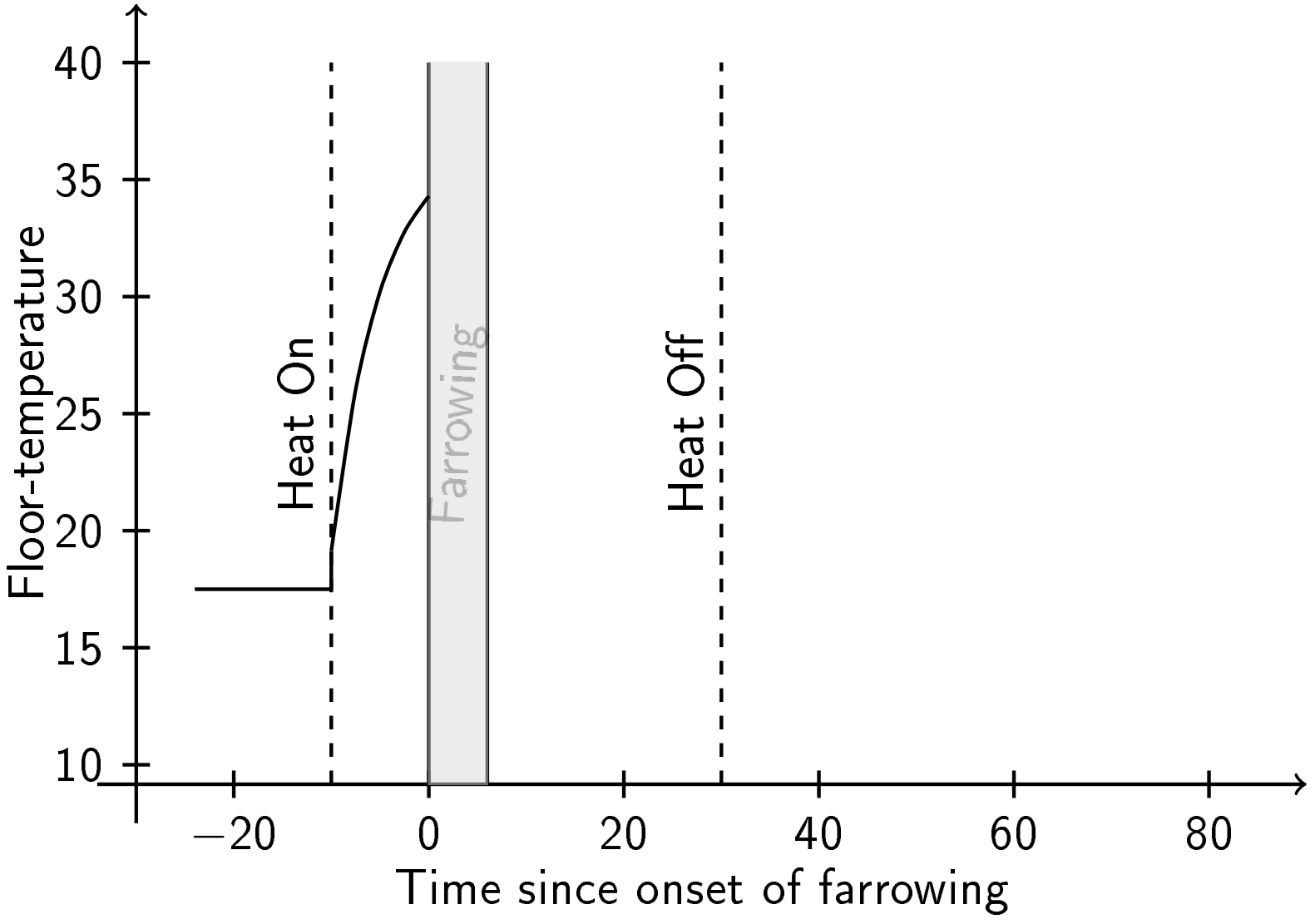

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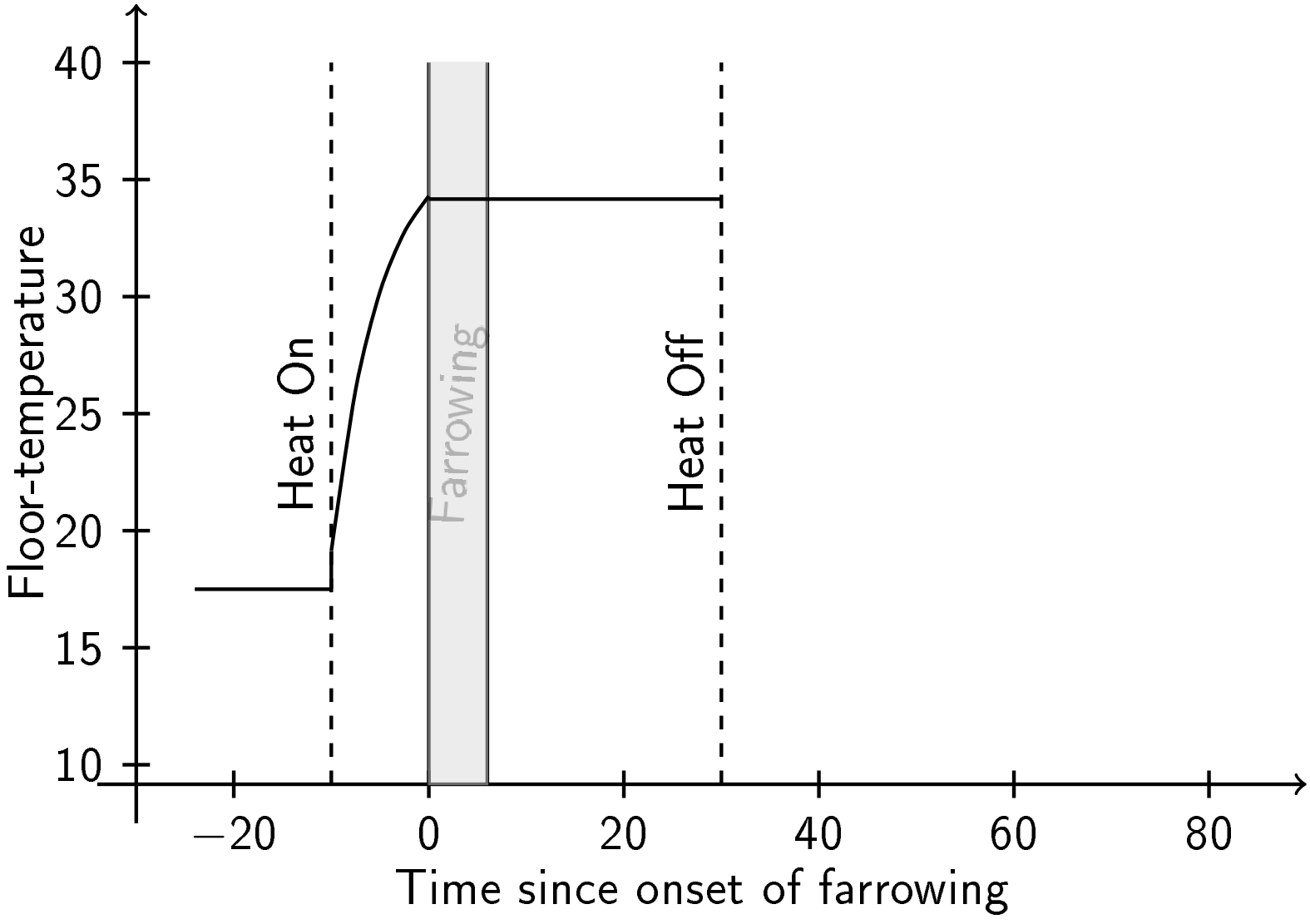

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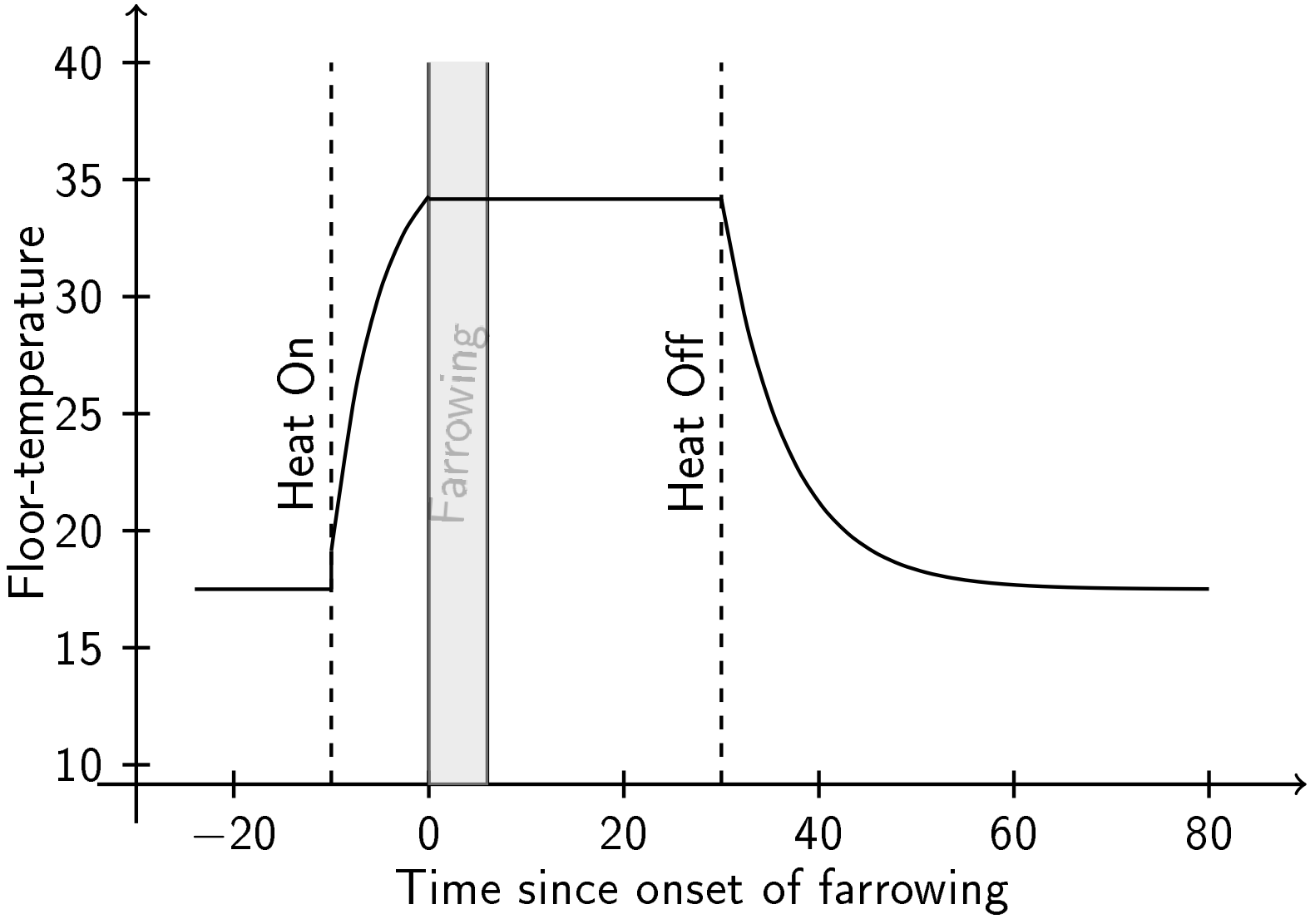

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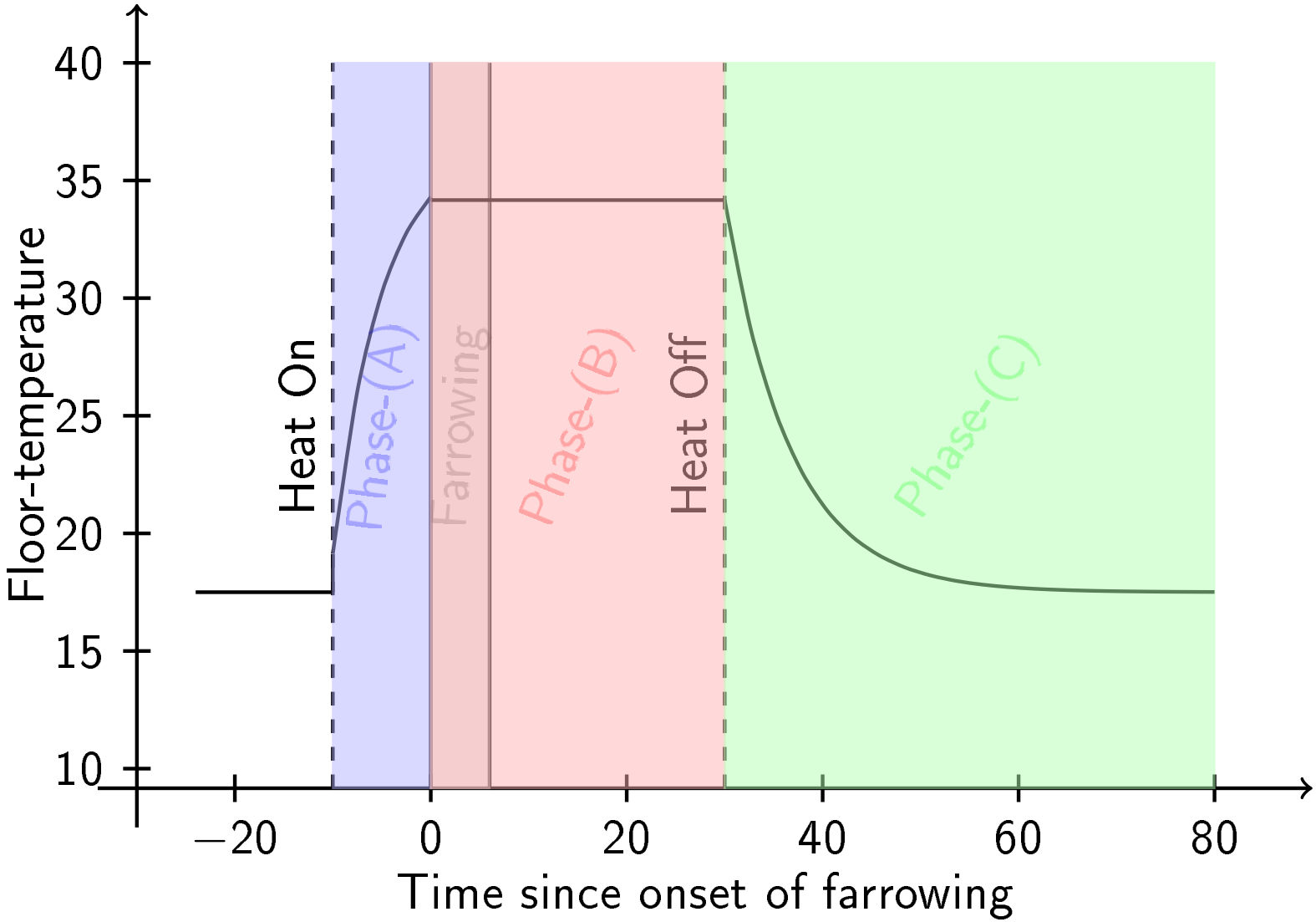

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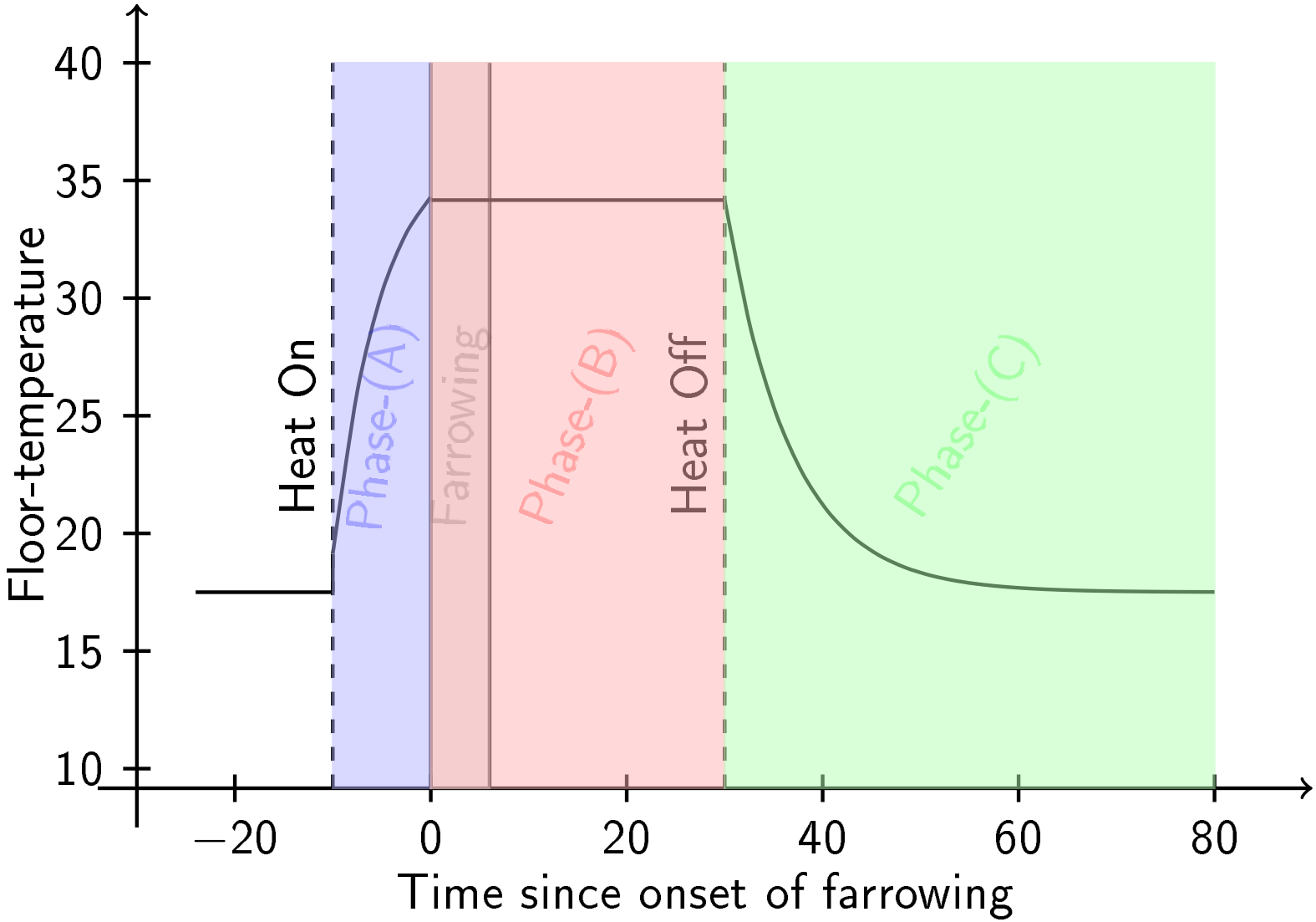

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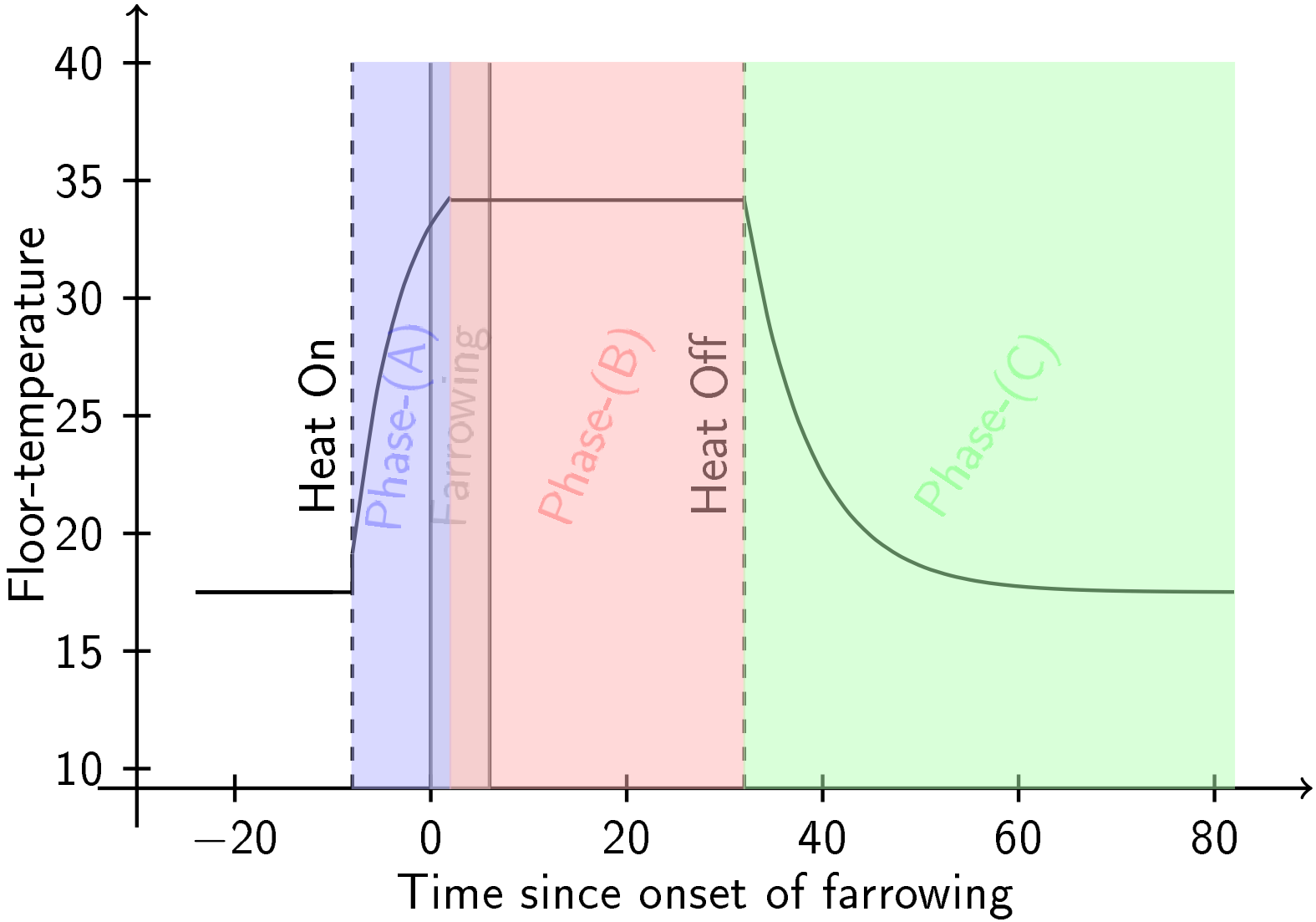
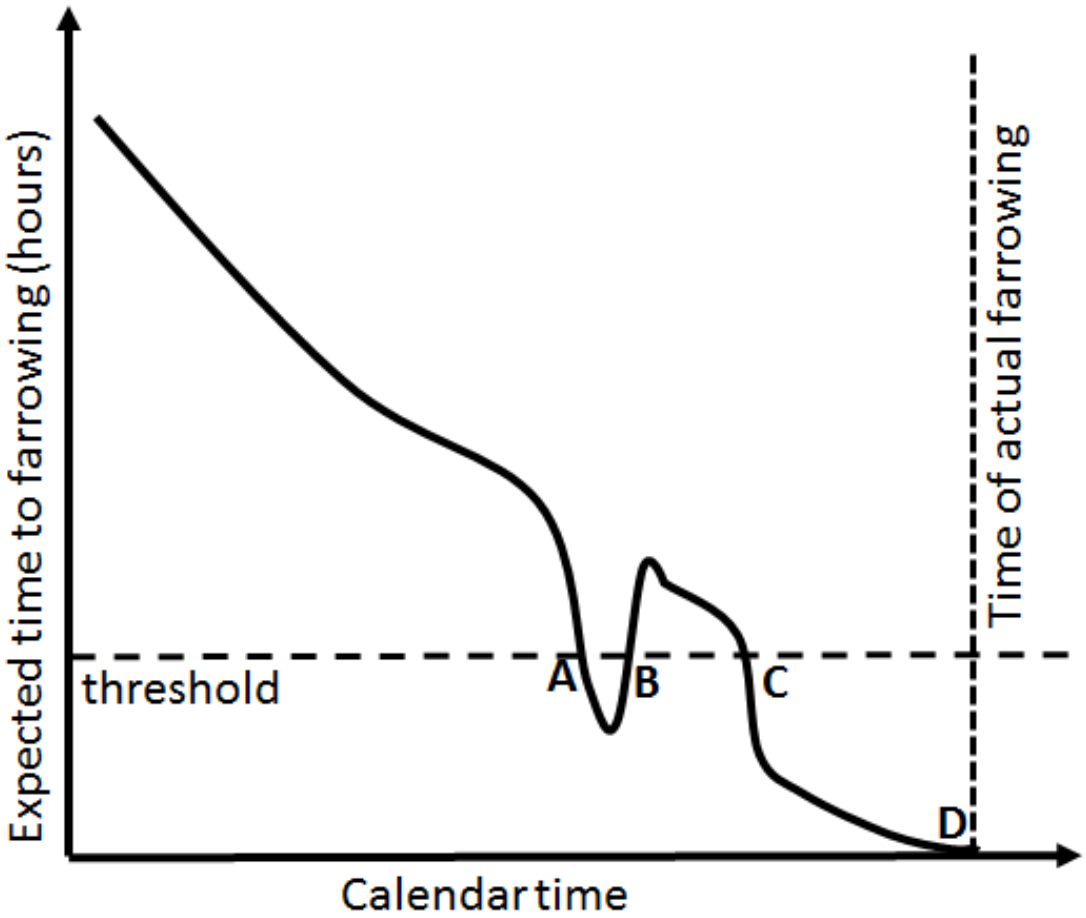


How to choose threshold???



Floor-heat regulation System

"Partially Observable Markov Decision Process (POMDP)"

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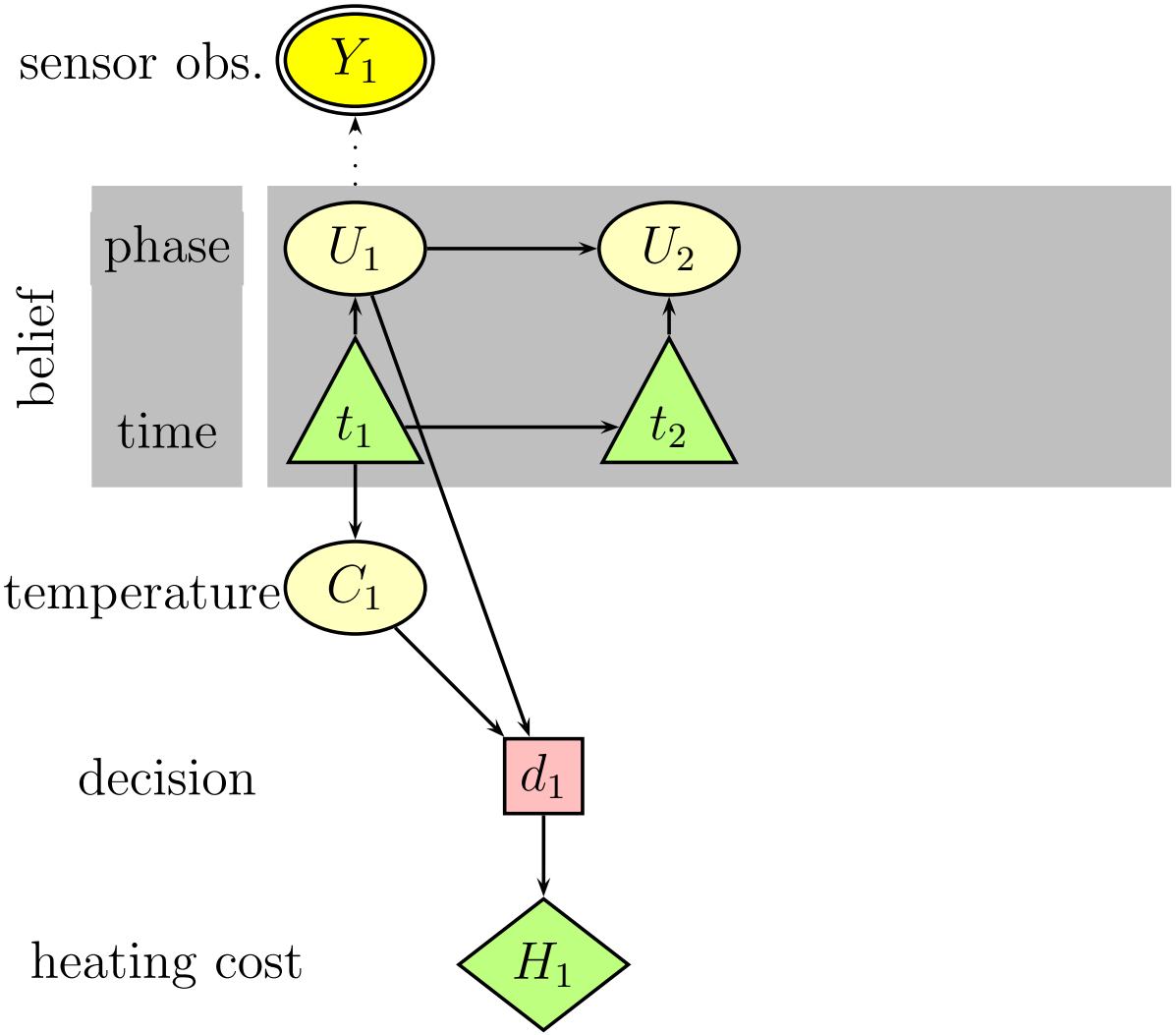

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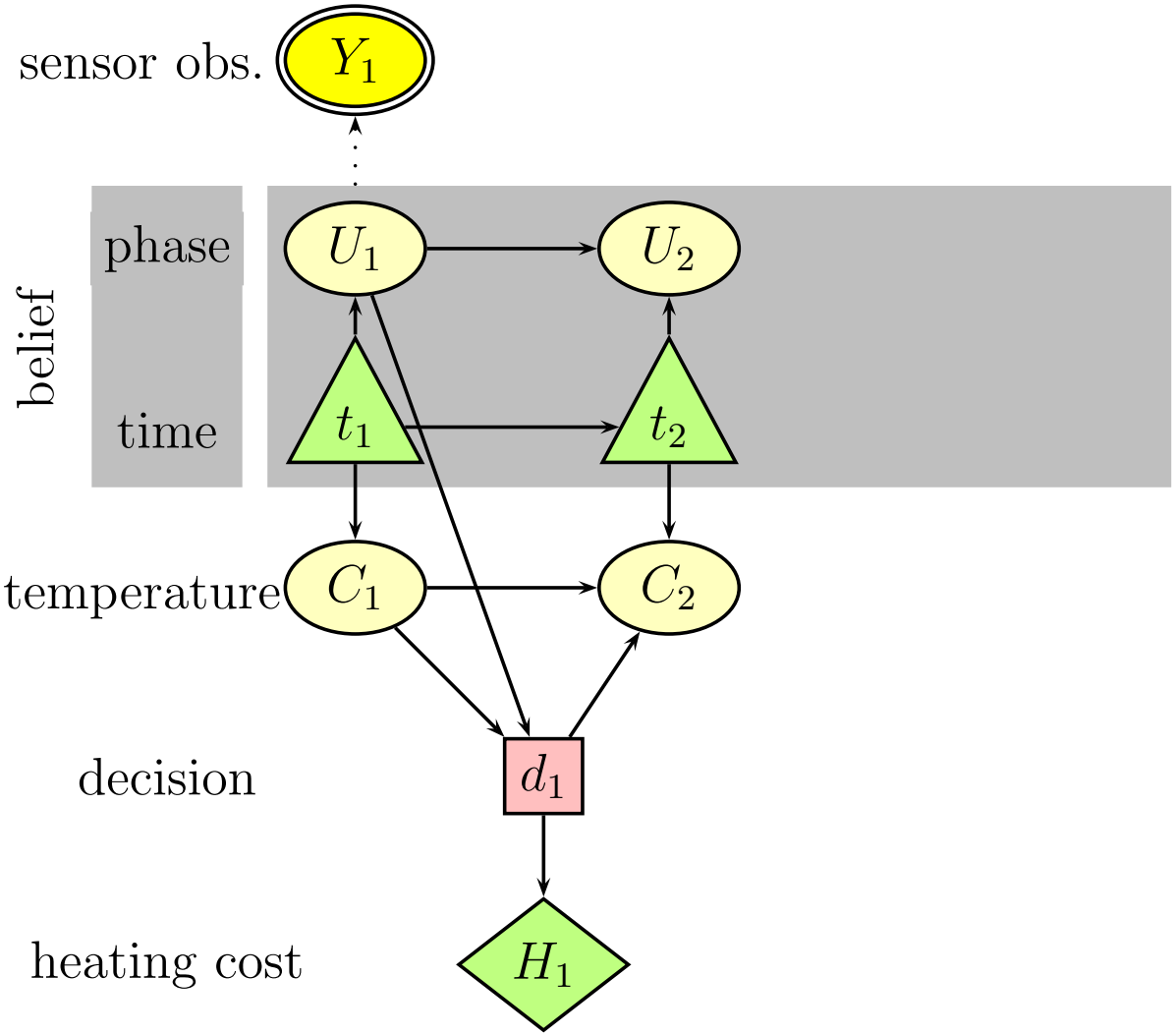

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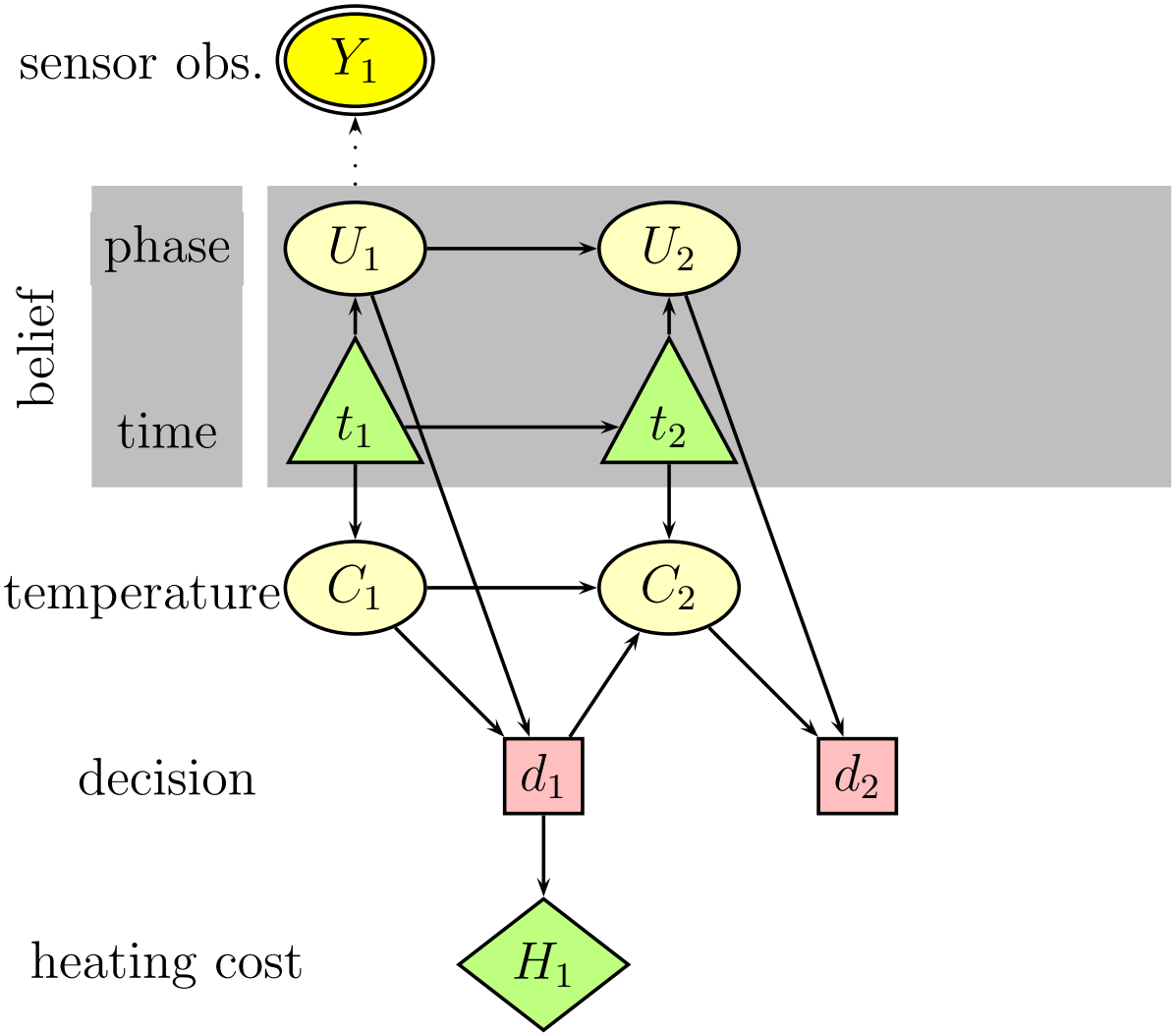

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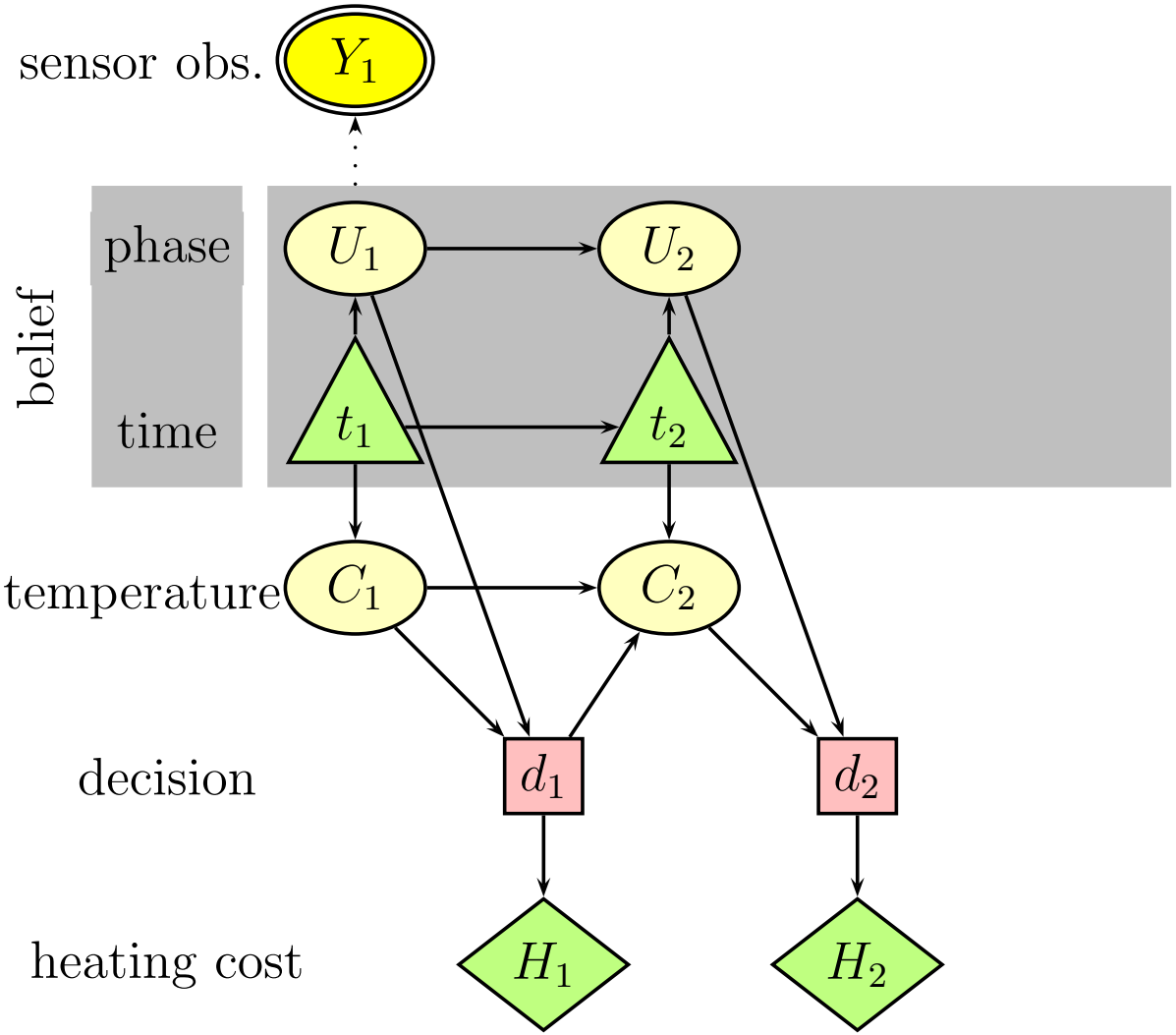

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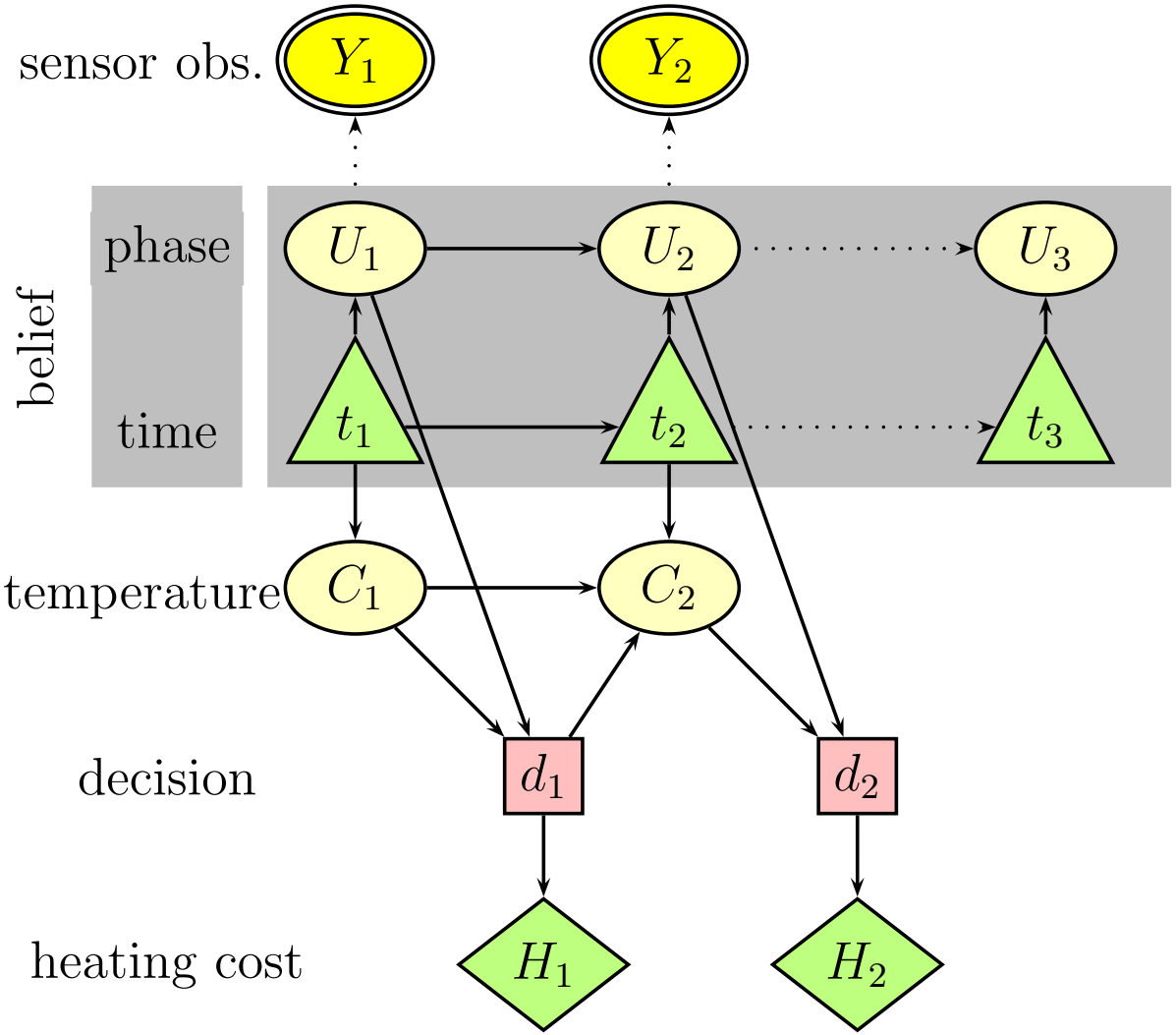

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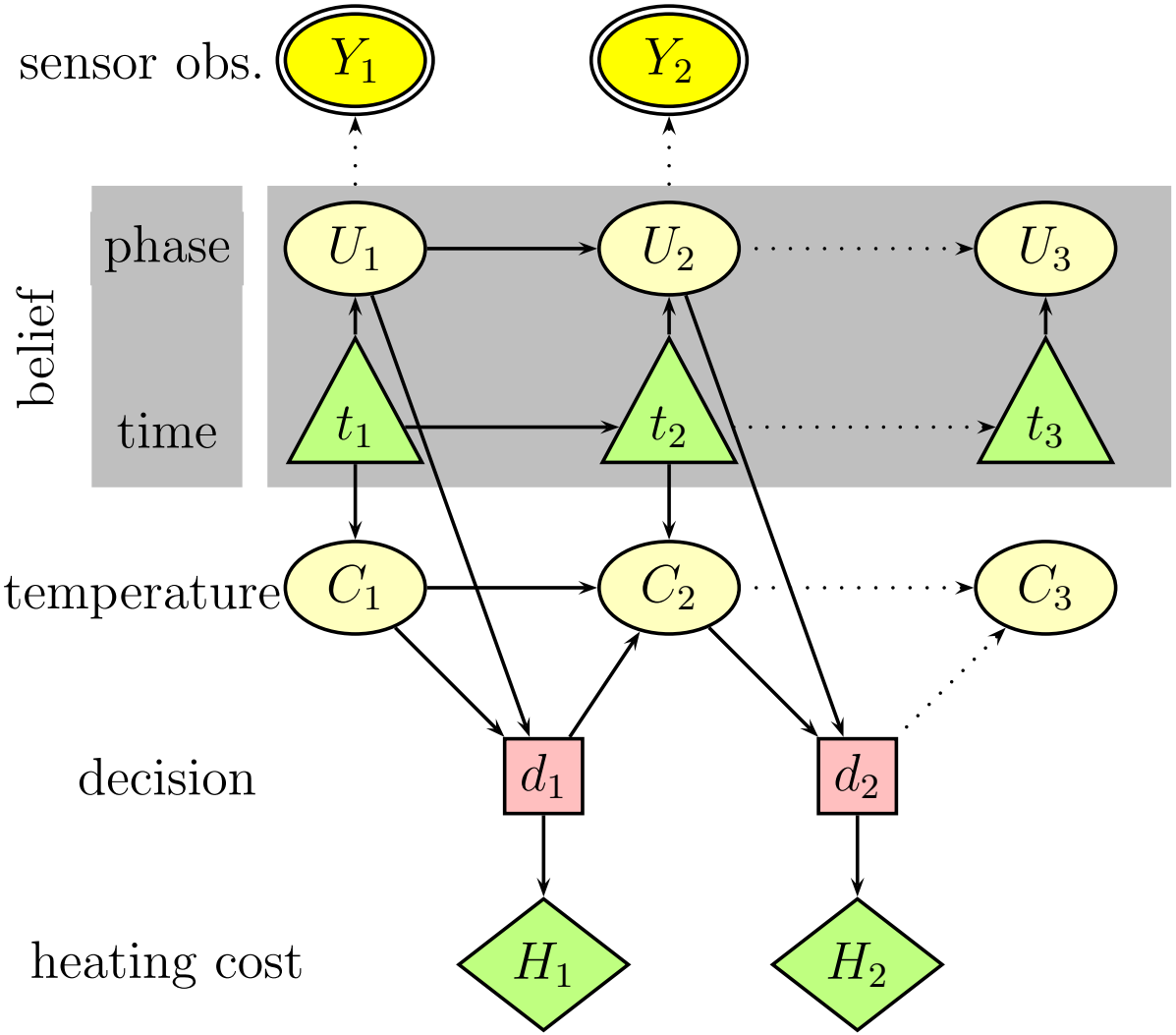

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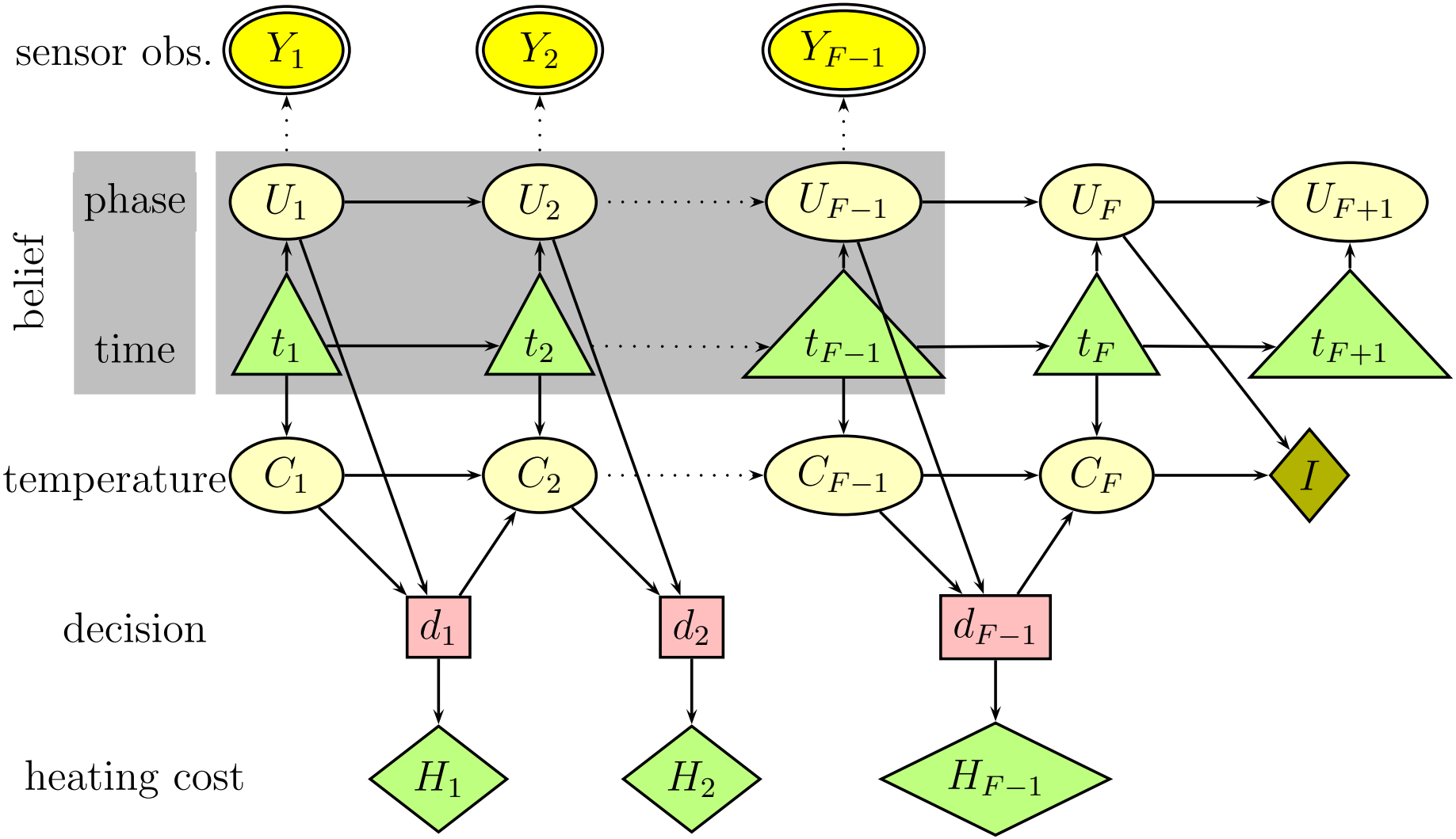


Approximate Solution

Approximate POMDP solution

- **Markov Decision Process** - optimization for known phases
- Value Iteration Method
  - Optimize the total expected utility
  - w.r.t. phase number and floor-temperature
- **Greedy Strategies**

MDP look-up decision table

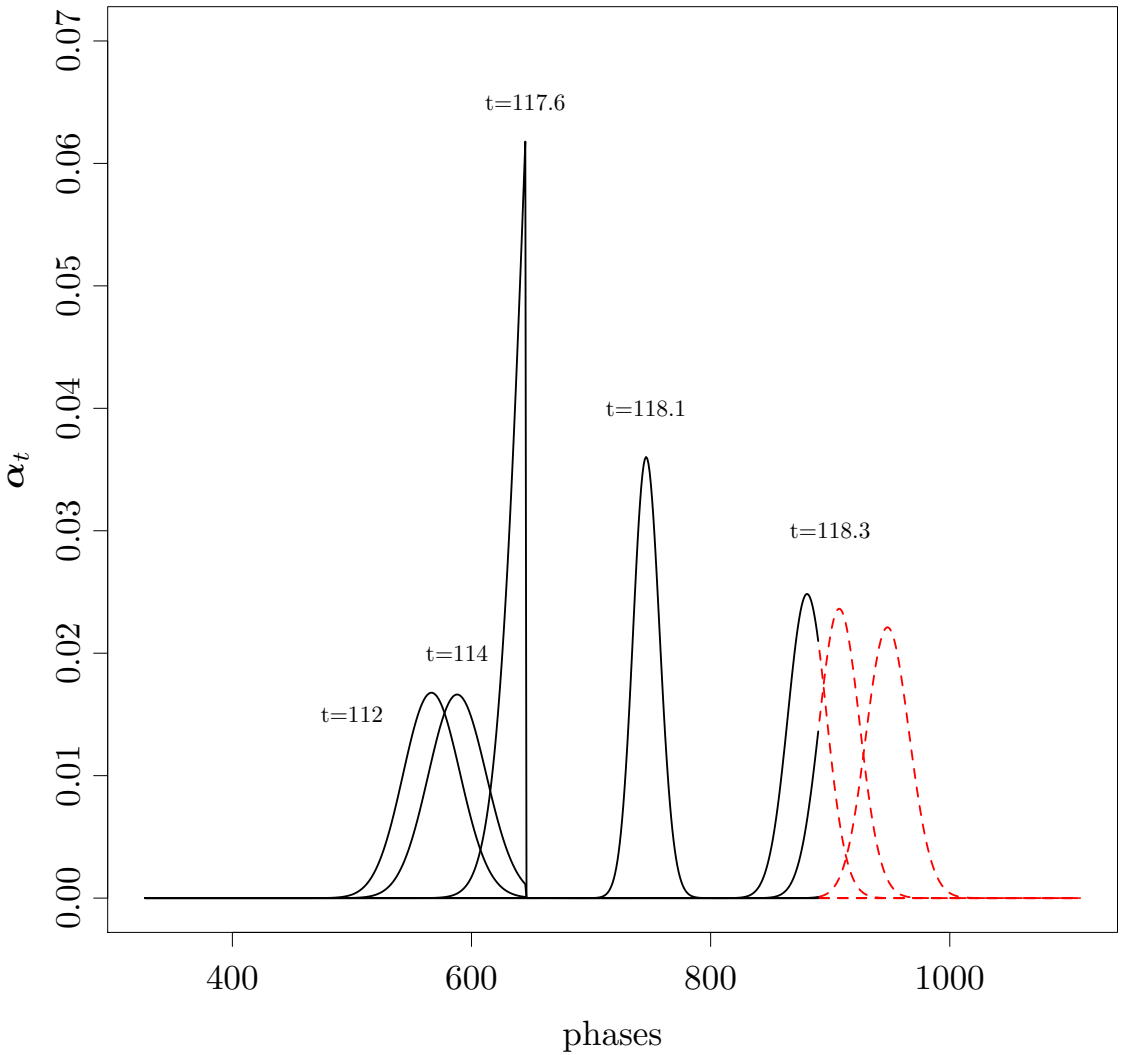
Approximate POMDP Solution

Floor-temperature	Behavioural Phase	$\Delta Q^{(opt)}$	**Decision**$^{(opt)}$
21	Phase-1		
21	Phase-2		
⋮	⋮		
21	Phase-1000		
22	Phase-1		
22	Phase-2		
⋮	⋮		
22	Phase-1000		
⋮	⋮		

*$\Delta Q^{(opt)}$: reward of heating

Approximating to POMDP

Decision Vs Belief state for the given floor-temperature



POMDP Greedy Strategies

- QMDP - expectation over all the phases

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- Most likely phase
- Random phase
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- Random action

POMDP Greedy Strategies

- QMDP - expectation over all the phases
- Most likely phase
- Random phase
- Voting
- Random action

*Above greedy strategies return almost identical rewards.

Robustness

POMDP for Floor-heat Regulation Strategy

- Decision tool is robust to the changes in room temperature,

Robustness

POMDP for Floor-heat Regulation Strategy

- Decision tool is robust to the changes in room temperature, energy supply,

Robustness

POMDP for Floor-heat Regulation Strategy

- Decision tool is robust to the changes in room temperature, energy supply, mortality model

Robustness

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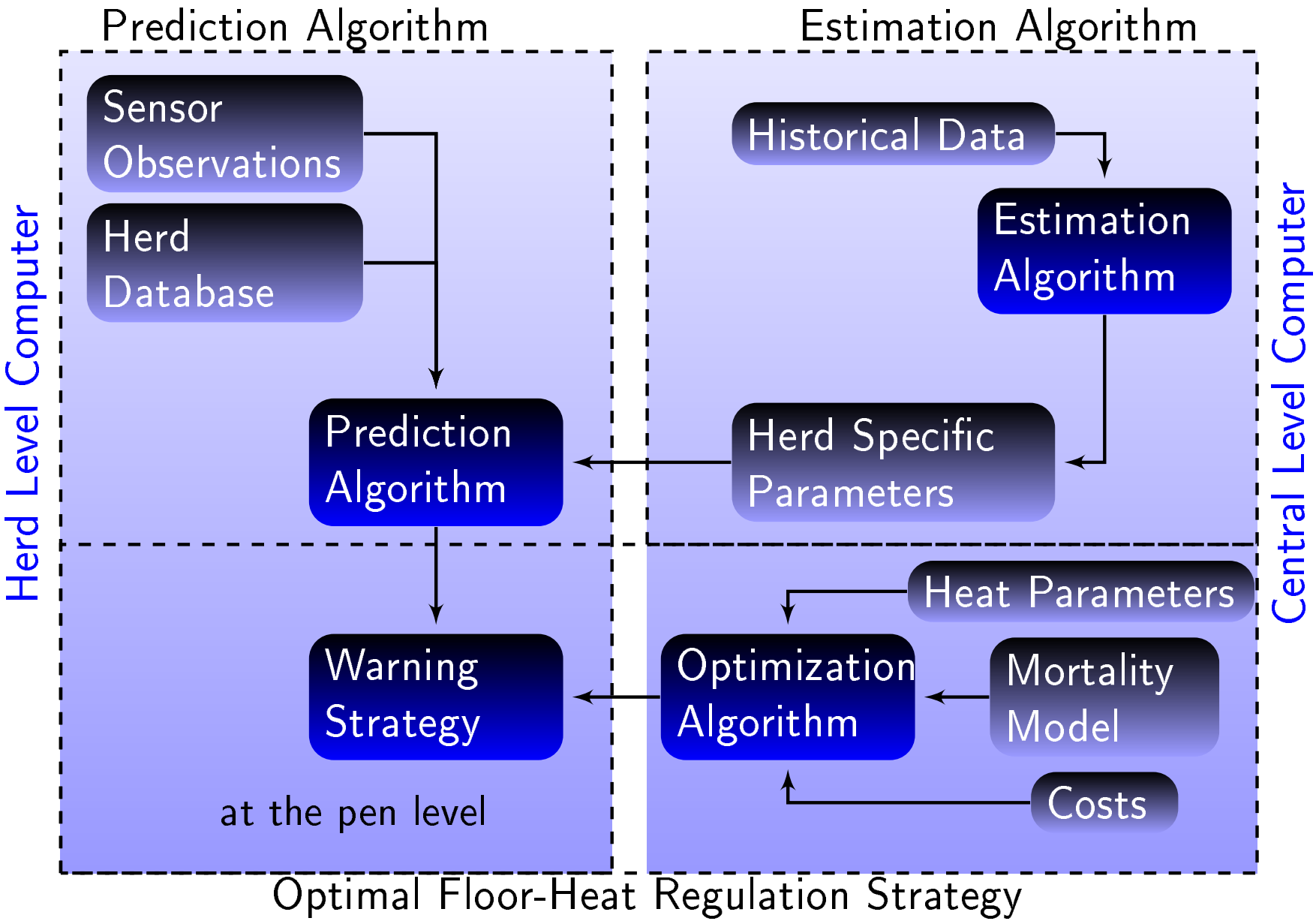
Robustness

POMDP for Floor-heat Regulation Strategy

- Decision tool is robust to the changes in room temperature, energy supply, mortality model and price of a piglet
- POMDP strategy performed better than simple heuristic strategy especially when the room-temperature and energy supply was varied
- POMDP does not suggest to turn on the heater if it is not beneficial

Final Remarks...

Desired System - data management to decision



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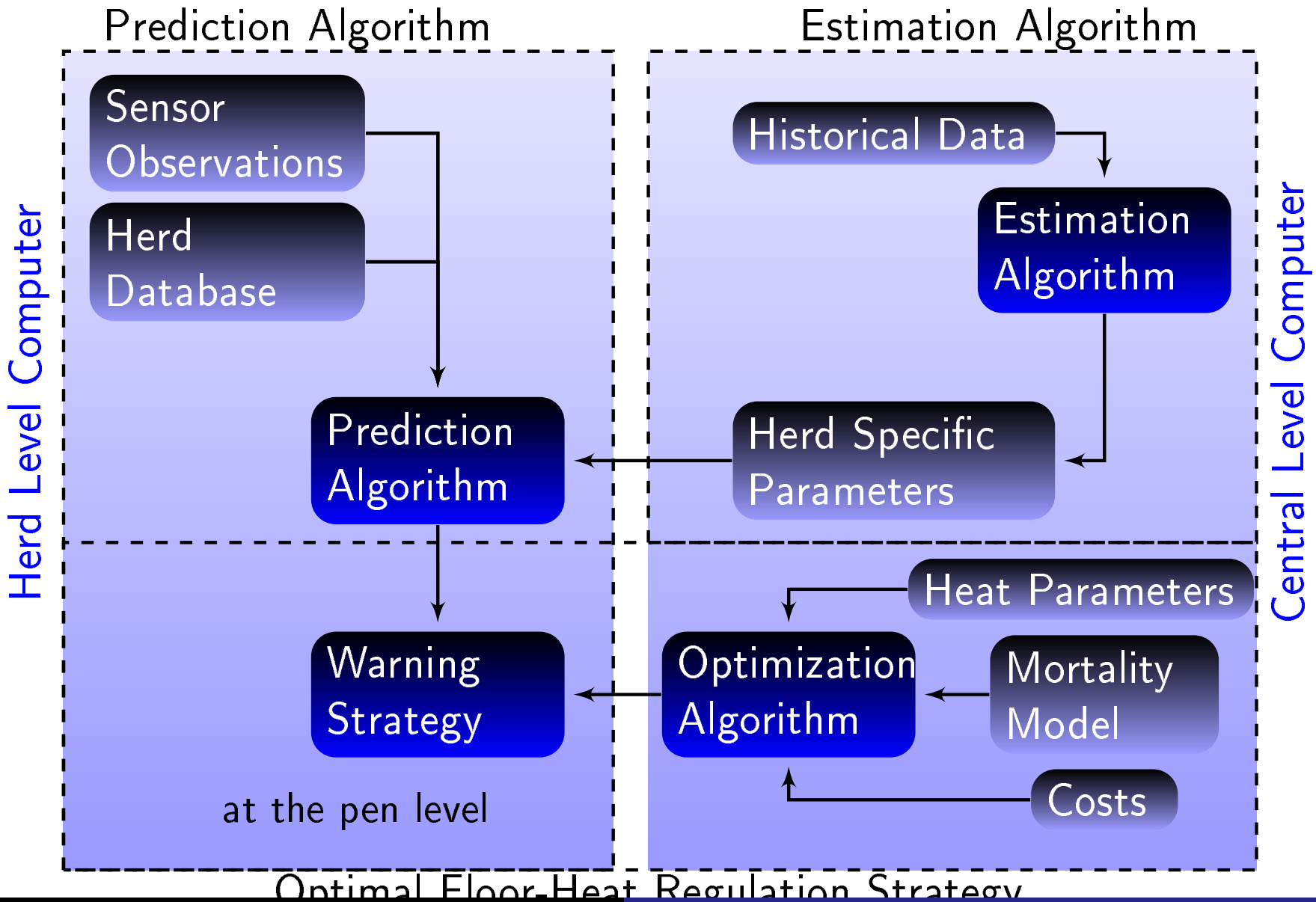

Future works...

Studying the corners of the desired system

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- Including farmer's observation on farrowing into model

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- Improving the methods and the calculation speed of Estimation algorithm

Future works...

Studying the corners of the desired system

- Including farmer's observation on farrowing into model
- Improving the methods and the calculation speed of Estimation algorithm
- Similar decision support system for other applications

Take home message...

Contributions

- Framework of an automated system starting from data management to decision The Intelligent Farrowing Pen
- Model for monitoring the pre-parturition behaviour of an individual sow
- Prediction of onset of farrowing - can directly calculate the expected time to farrowing for an individual sow
- Prediction model as the kernel of a decision support system
- Modelling sows diurnal rhythm in sensor observations
- Integrating information from several sensors

The Intelligent Farrowing Pen