LSST Feature-based Scheduler

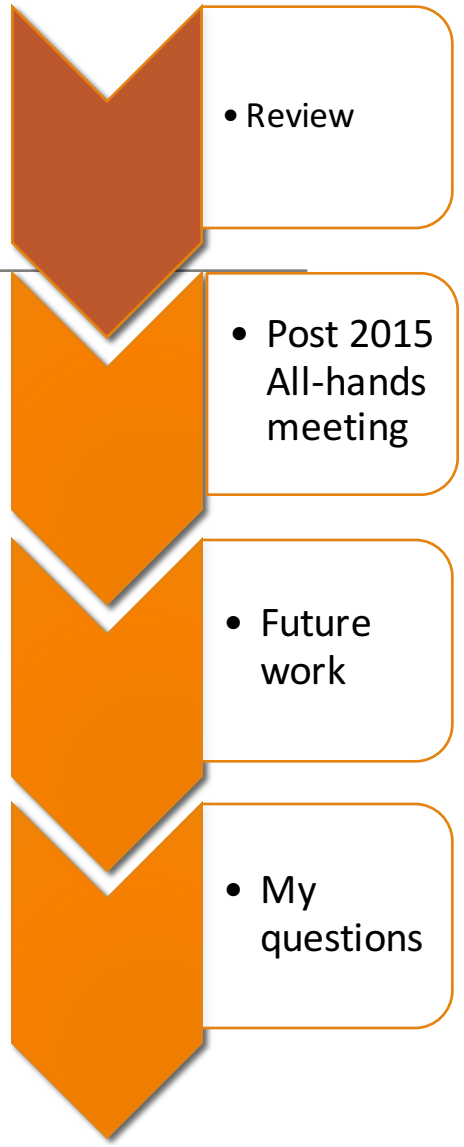
ORFE Operations Research & Financial Engineering

PRINCETON UNIVERSITY

Review

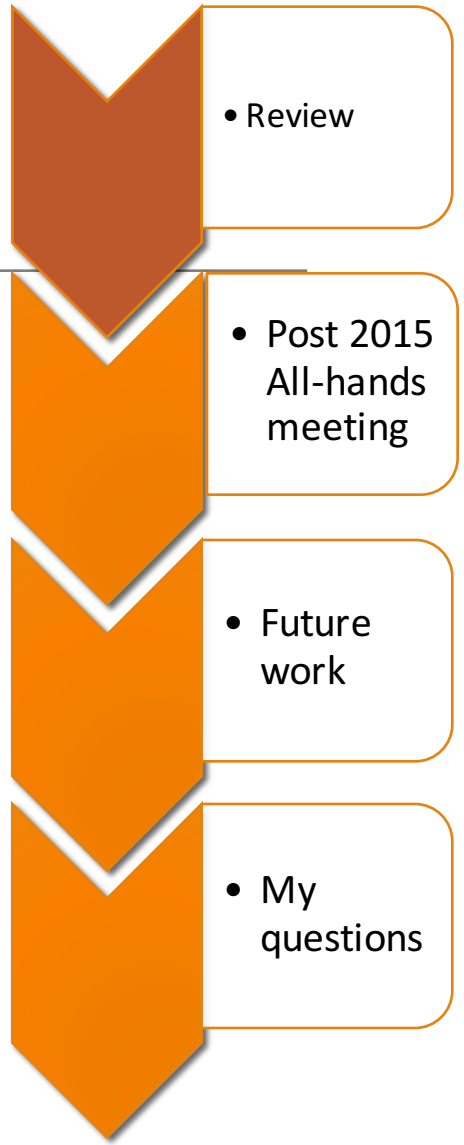
Problem setting:

- Sequential decision making problem
- Measurable Objectives:
  - Maximum cumulative co-added depth
  - Uniform coverage
  - Scientific metrics
- Constraints:
  - Revisit window
  - Visibility
  - Scientific constraints



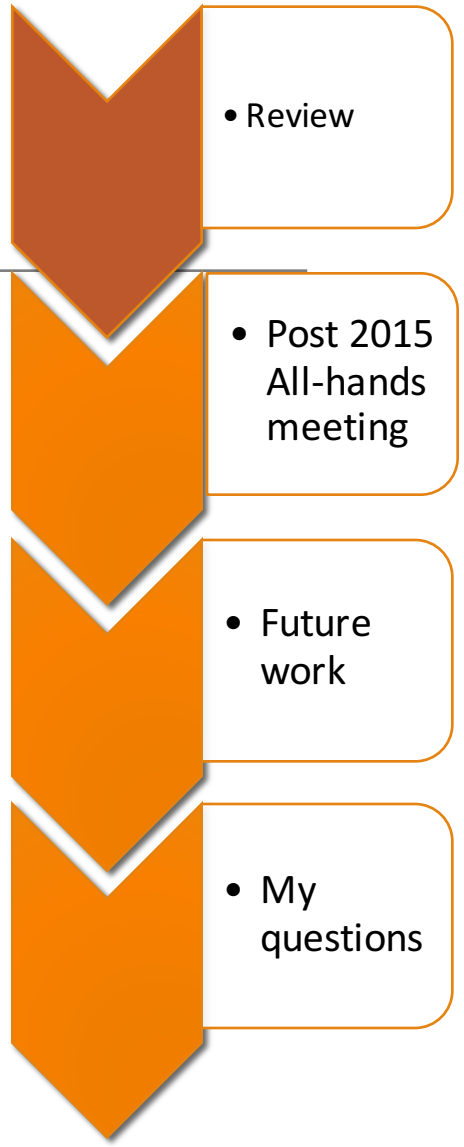
Review: Objectives (for One night scheduling)

- Maximum cumulative co-added depth
  - (Maximize) Number of the visits
  - (Maximize) Average of the field's separation with the Moon
  - (Maximize) Average of the observation altitude
- Uniform coverage
  - (Minimize) The number of fields that are missed for the second visit
- Scientific metrics
  - -

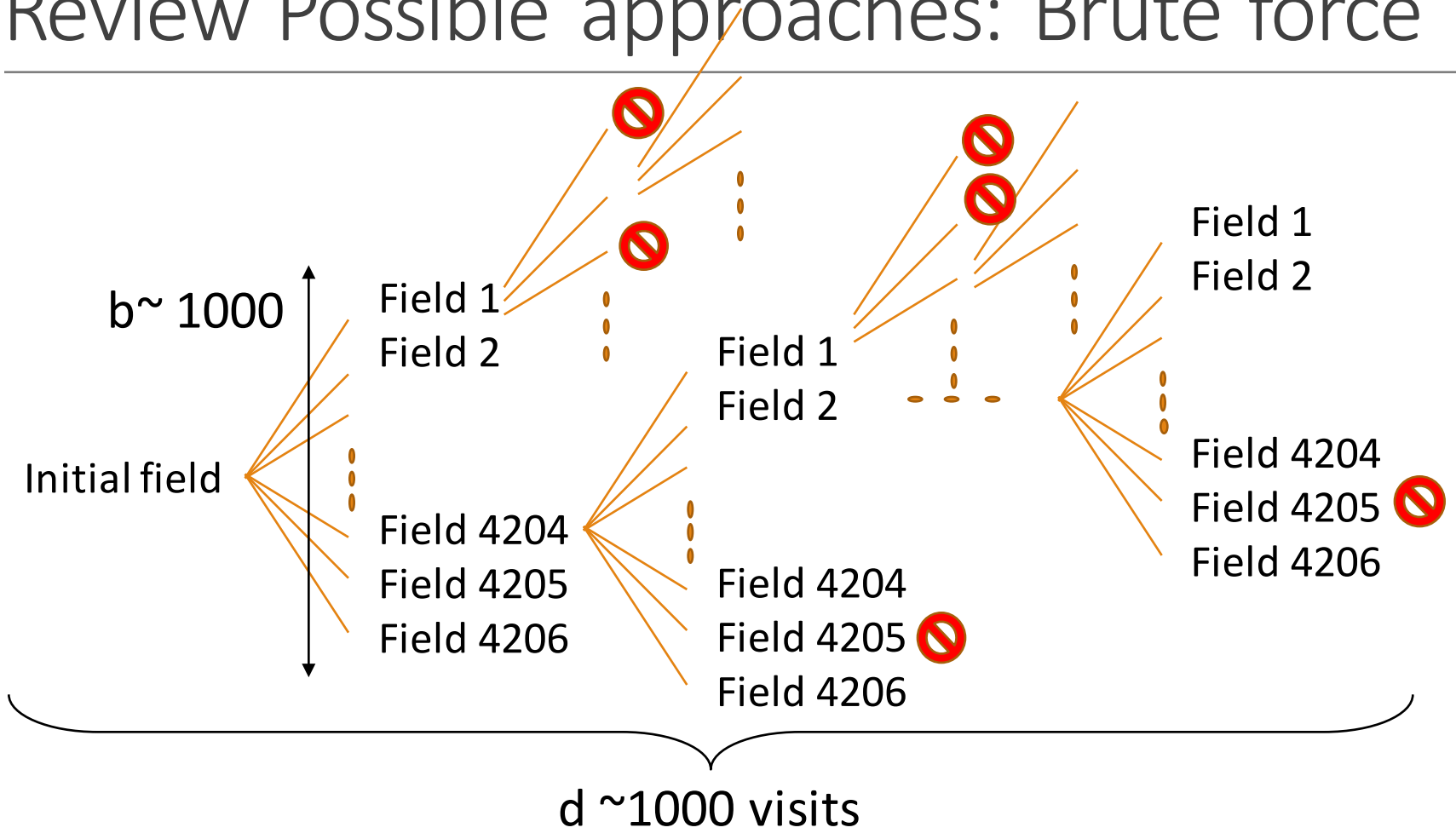


Review: Constraints (for One night scheduling)

- Revisit window
  - Fixed revisit window of 15-60 minutes for all fields
- Visibility
  - Avoid fields with alt < 0
  - Avoid fields below 1.4 airmass
- Scientific constraints
  - -



Review Possible approaches: Brute force

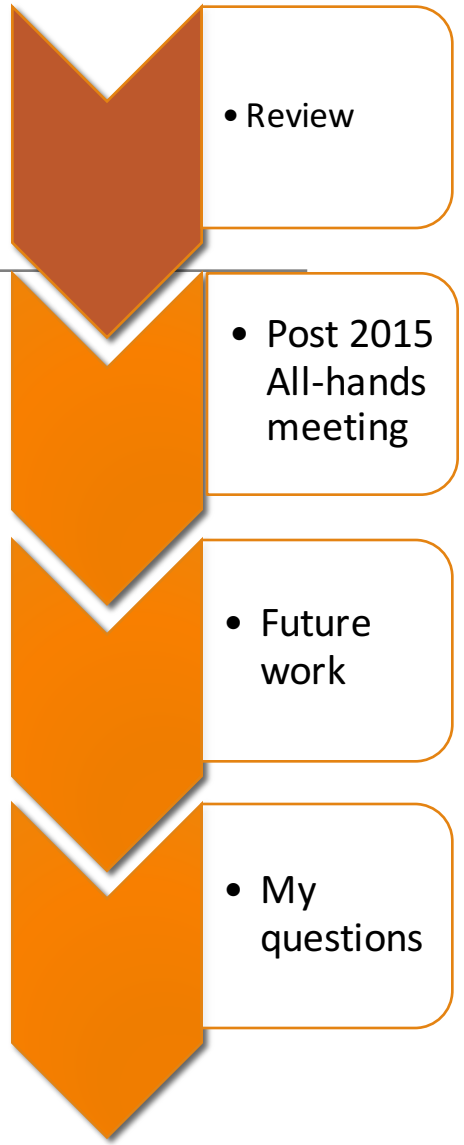


- Review
- Post 2015 All-hands meeting
- Future work
- My questions

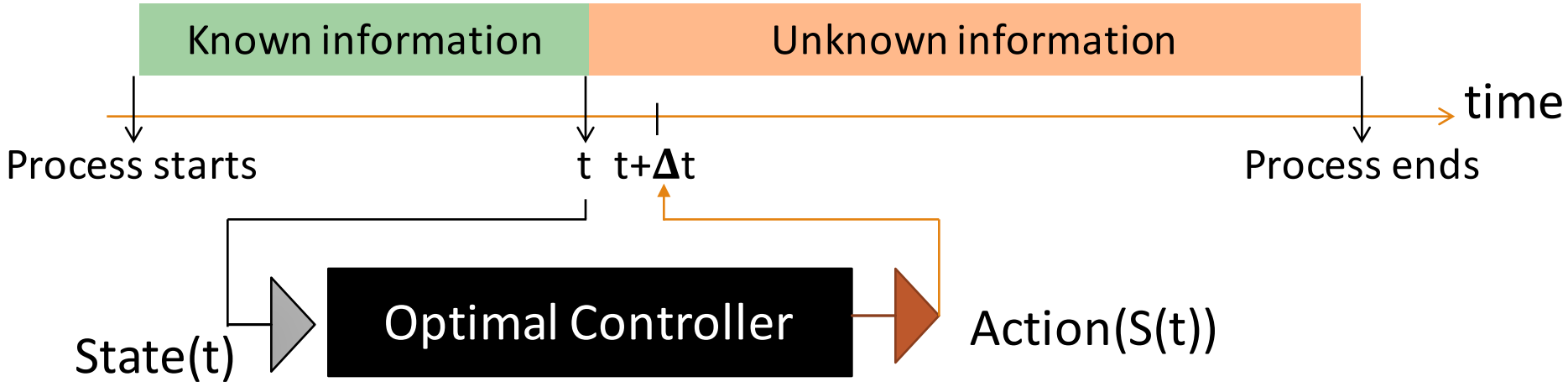
Review Possible approaches: Optimal Control

Framework:

- S(t): state of the system: Full description of the current status
  - History, Current cloud coverage, sky brightness
- A(S(t)): Action to be taken for transition to the next state
  - Next field $\in$ { i | i is a feasible field at t }
- Optimal Controller: mapping: {S} -> {A}
- Underlying dynamic of the disturbances:
  - Probability distribution of the clouds
  - Sky brightness



Review Possible approaches: Optimal Control



Achieves the global (expected) optimum of the objective.

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Review Possible approaches: Approximate optimal control

Approximation 1:

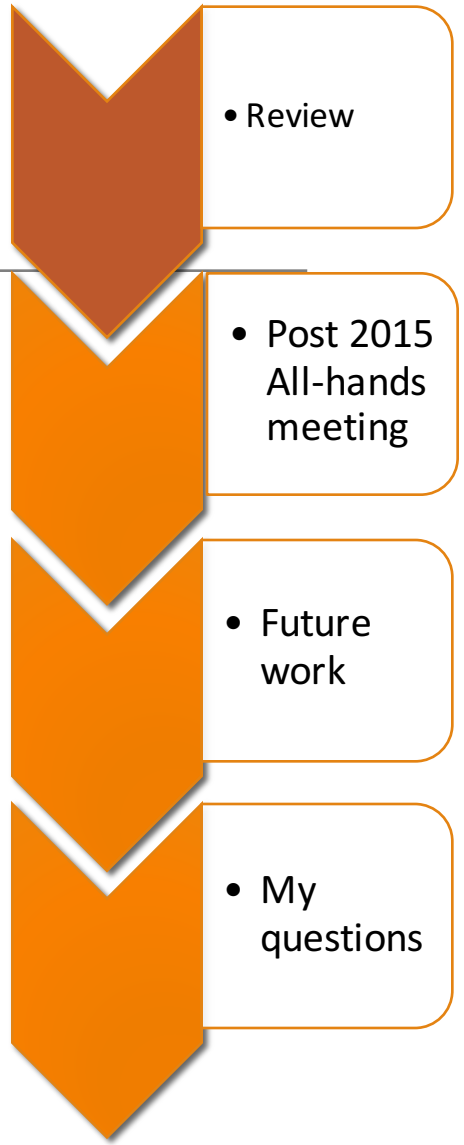
- ~~S(t): state of the system: Full description of the current status~~
- F(t): features of the system
  - For instance: ~~History,~~ time of the last two visits of each field
- A(S(t)): Action to be taken for transition to the next state
  - Next field $\in$ { i | i is a feasible field at t }

Approximation 2:

- Optimal Controller: mapping: {S} -> {A} : **Assuming structure**
  - For instance: Linear cost function

Approximation 3:

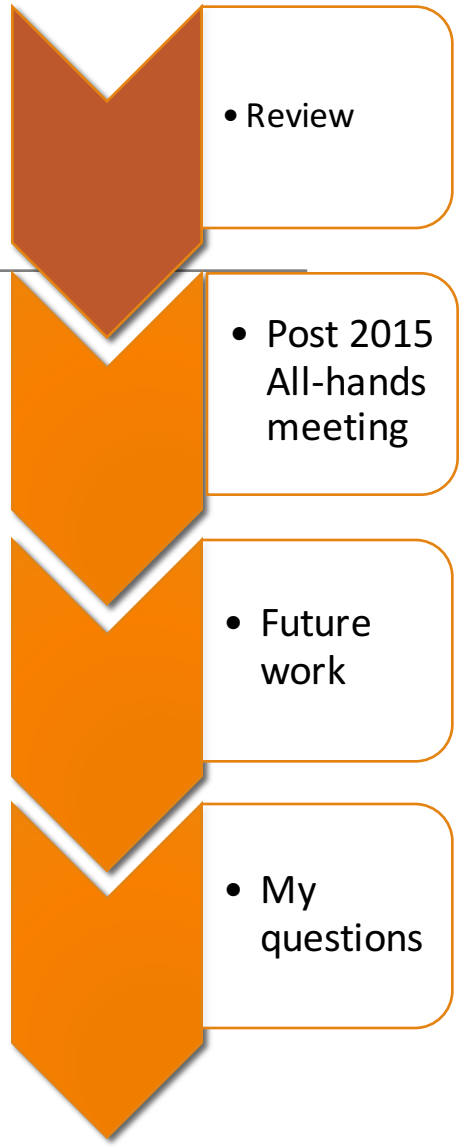
- Underlying dynamic of the disturbances: **Approximate dynamic**
  - Probability distribution of the clouds
  - Sky brightness



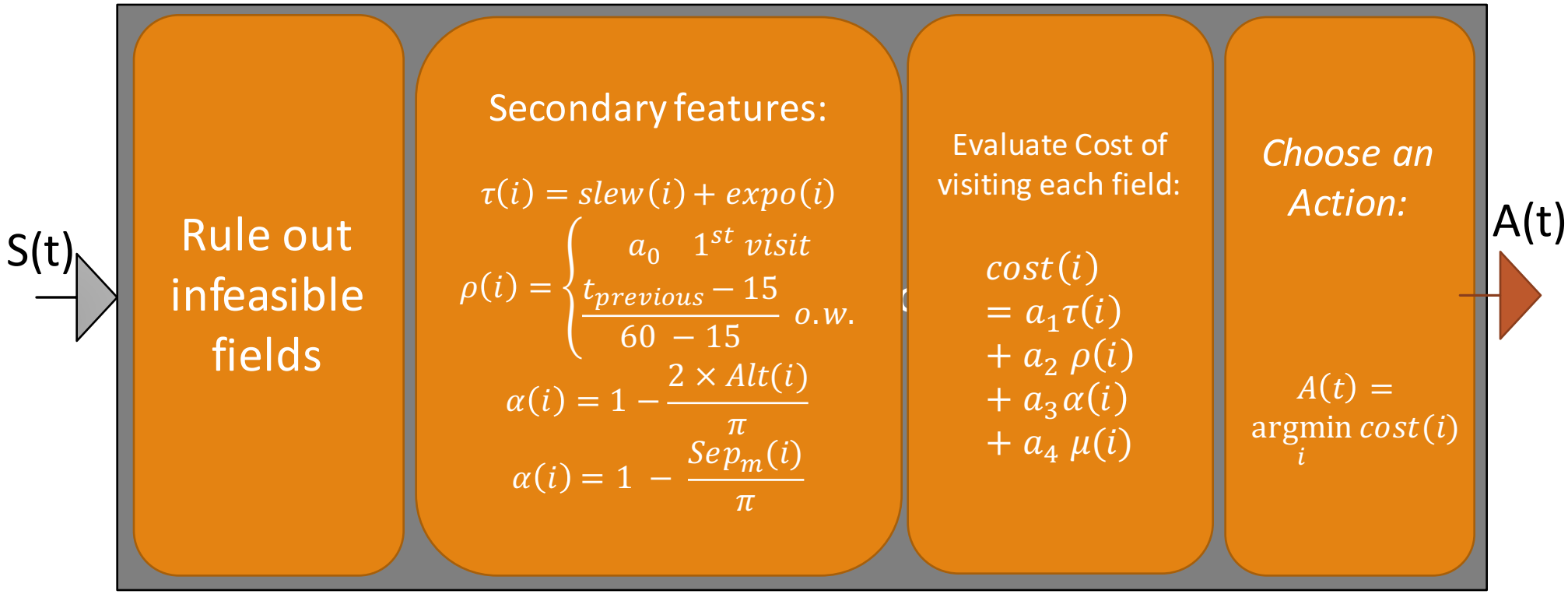
Review: Feature space

For each field: i , at current time: t

- number of previous visits, time of the last visit until t: $Hist(i,t)$
- Slew time from the current field: $Slew(i)$
- Exposure time needed: $Expo(i,t)$
- Altitude and Azimuth: $Alt(i,t), Az(i,t)$
- Air-mass constraint: $Airmass(i,t) \in \{0,1\}$
- Separation with the Moon: $Sep_M(i,t)$



Review: Controller



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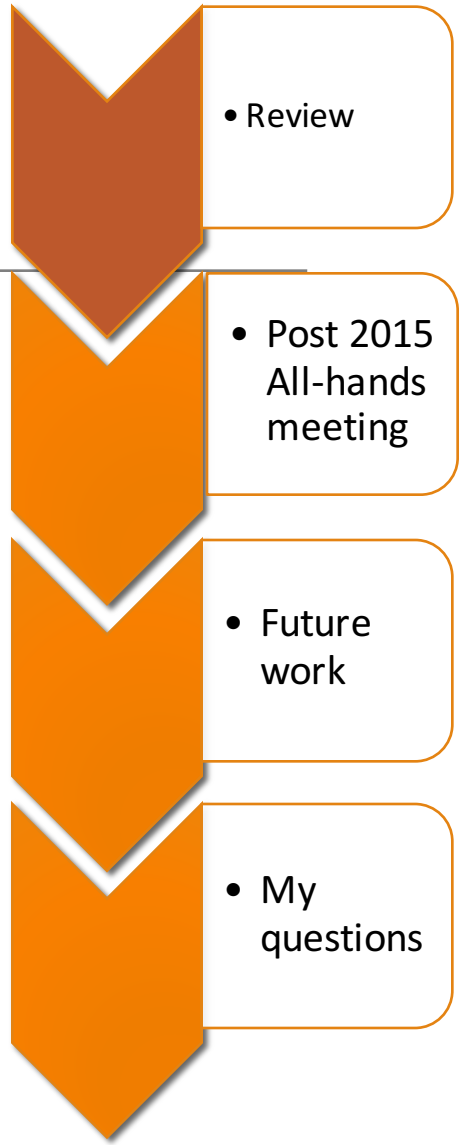
Controller parameters: $(a_0, a_1, a_2, a_3, a_4)$

Review capabilities

- Handles individual constraints/cost evaluations for individual fields
  - For field I, revisit window of 10-20 minutes is preferable
- Handles intervention
  - We can take an action different from A(t), and continue with the controller for t+Δt
- Flexible trade-off between optimality and computational effort
  - Using categories of nights to train or an average night
- Flexible trade-off between optimality and model accuracy
  - If co-added depth was not available, number of the previous visits would also work.

Review: Optimization

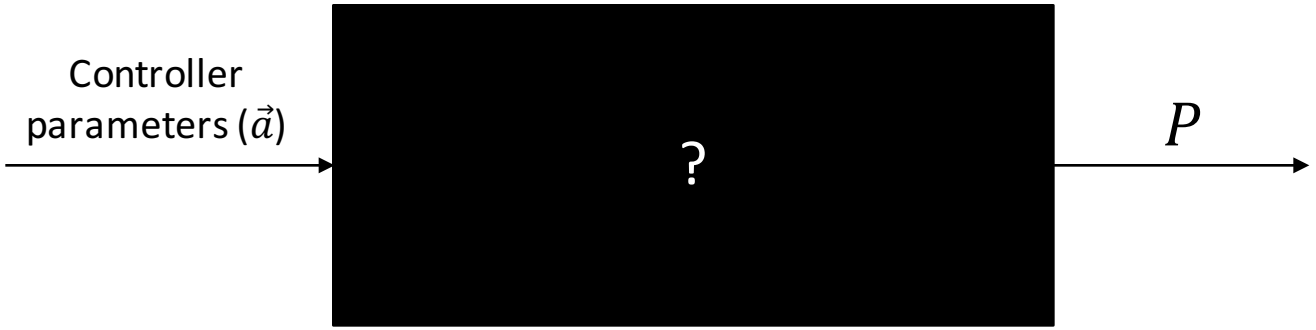
- Objective function: Telescope performance:
  - Maximum cumulative co-added depth
  - Uniform coverage
  - Scientific metrics
- Variables: Controller parameters ($\vec{a}$)
- Constraints: Regularization of the parameters
  - For instance: $\vec{a} \in cube\ or\ simplex$



Review: Performance function

- Measurable Values at the end of the observation
  - The number of fields visited twice: N_{twice}
  - The number of fields that are missed for the second visit: N_{once}
  - Average of the observation altitude: $\overline{Alt}$
  - Average of the field's separation with the Moon: $\overline{Sep_M}$

$$P \coloneqq 2\times \mathrm{N}_{\mathrm{twice}} - 1\times \mathrm{N}_{\mathrm{once}} + 5\times\overline{Alt} + 3\times\overline{Sep_M}$$



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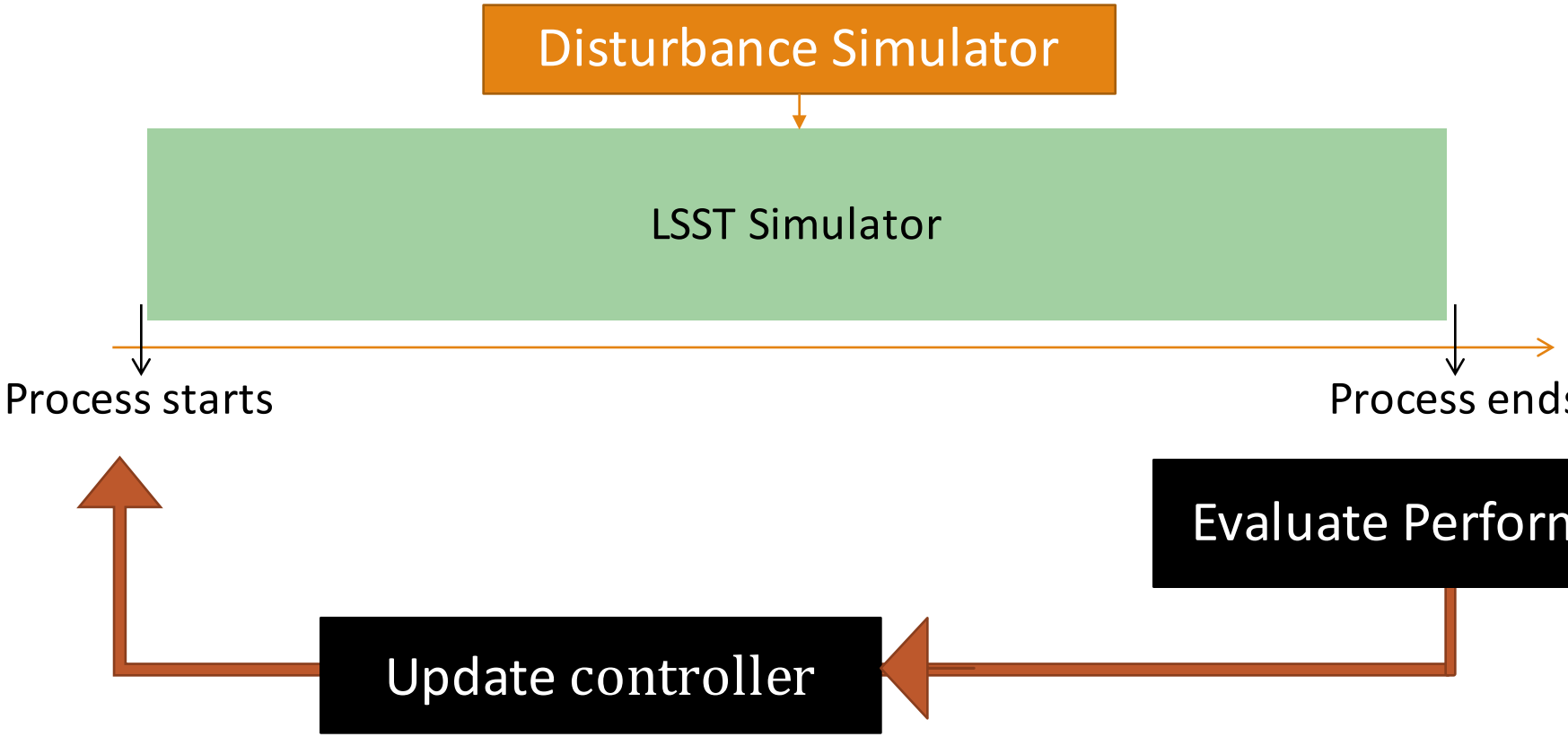
Review: Supervised learning (SL)



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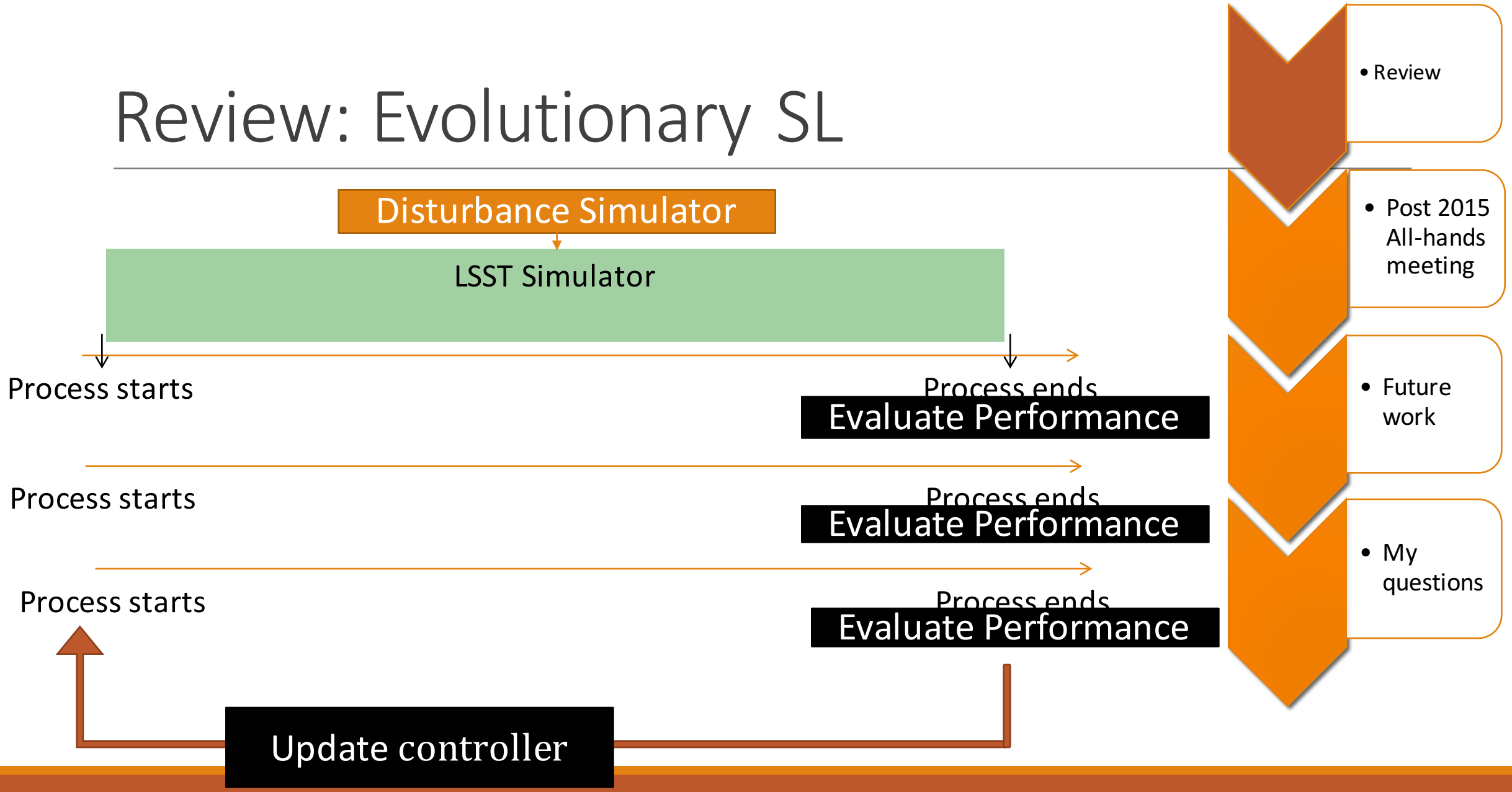
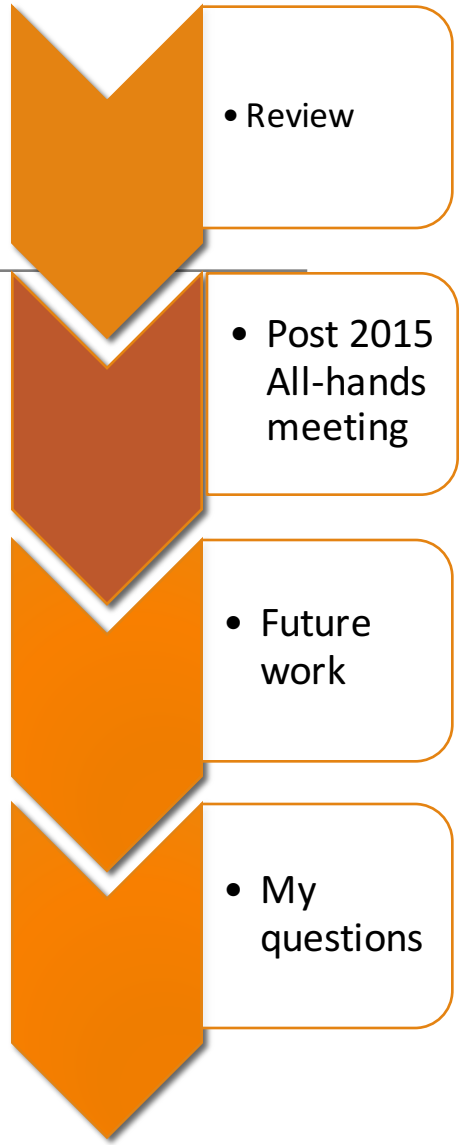
Review: Evolutionary SL



Post 2015 All-hands meeting

- Improve approximations
  - Approximation 1: State space approximation
  - Approximation 2: Controller structure
  - Approximation 3: Underlying dynamics
- Implementation
  - Piecewise constant features
  - SQLite output compatible
  - LSST-specific DE implementation



State space approximation: Feature space

$f_1(i,t)$:= slew time of the telescope from current direction to the i'th field direction at t,

$f_2(i,t)$:= time since the last visit of the i'th field until t,

$f_3(i,t)$:= altitude of the center of i'th field at t,

$f_4(i,t)$:= hour angle of the center of i'th field at t,

$f_5(i,t)$:= measured co-added depth of the i'th field up to t,

$f_6(i,t)$:= time remaining for the i'th field to become effectively invisible, from t,

$f_7(i,t)$:= sky brightness at the direction of i'th field at t,

$f_8(i,t)$:= duration of the i'th field visibility for the rest of the current year,

$f_9(i,t)$:= (n1 (i, t), n2 (i, t), . . . , n6 (i, t)), a vector of 6 elements, where nk (i, t) is the number objects in the i'th field that belong to the science program k. There are 6 science programs:

$f_{10}(t) \in$ {u,g,r,i,z,y},filter in use at t,

$f_{11}(i,t) \in$ {0, 1}, 1 if the i'th field is effectively covered by an unacceptable high air-mass, clouds, Moon, and all other temporarily covering objects at t, 0 otherwise.

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Controller structure

Possibility 1: Sophisticated secondary features + linear combination

- $F_1(i,t) \propto f_1(i,t)$
- $F_2(i,t) \propto f_5(i,t)$
- $F_3(i,t) \propto \alpha_1 \log\big(f_3(i,t)\big) + \alpha_2\ BD\big(f_{10}(t)\big) \times f_3(i,t) + \alpha_3 \log(f_7(i,t))$
- $F_4(i,t) \propto \dfrac{\sum_{k=1}^{6} n_k(i,t) \times \frac{IP_k}{\pi} \tan^{-1}\left(\frac{f_2(i,t) - UF1_k}{UF2_k} \times \frac{365}{f_8(i,t)} + \frac{\pi}{2}\right)}{\sum_{k=1}^{6} n_k(i,t)}$
- …

$$Cost(i,t) = \sum a_j \times F_j$$

➢ More knowledge, Less learning effort

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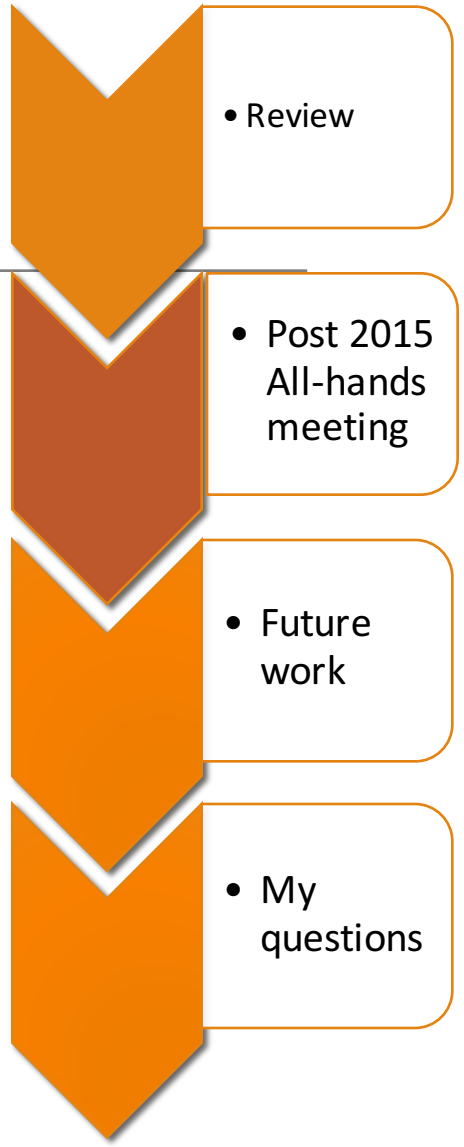
Controller structure

Possibility 2: raw (and just inclusive) features + sophisticated combination

Example of sophisticated combination: Neural Network, CNN, Model reduction of extended binary features

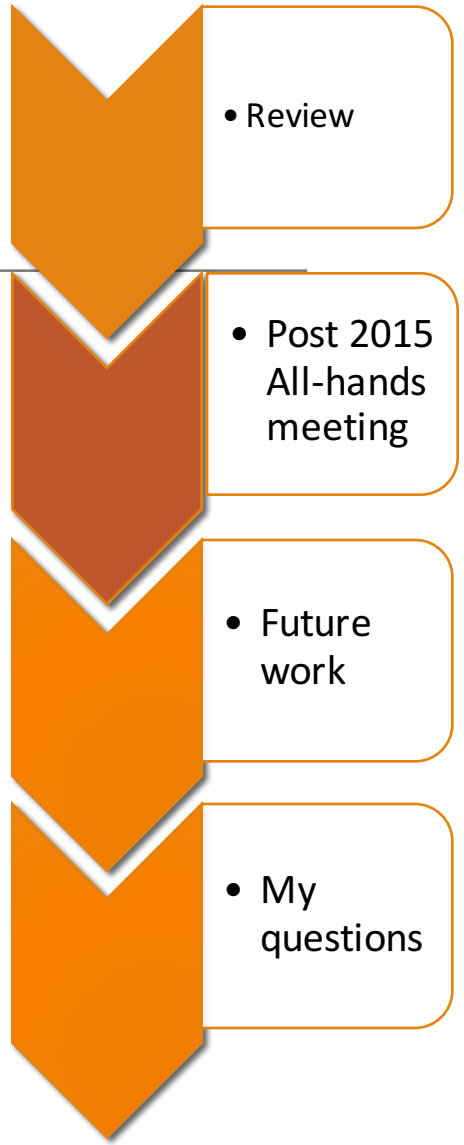
➢ Less knowledge, More learning effort

Possibility 3: A hybrid design



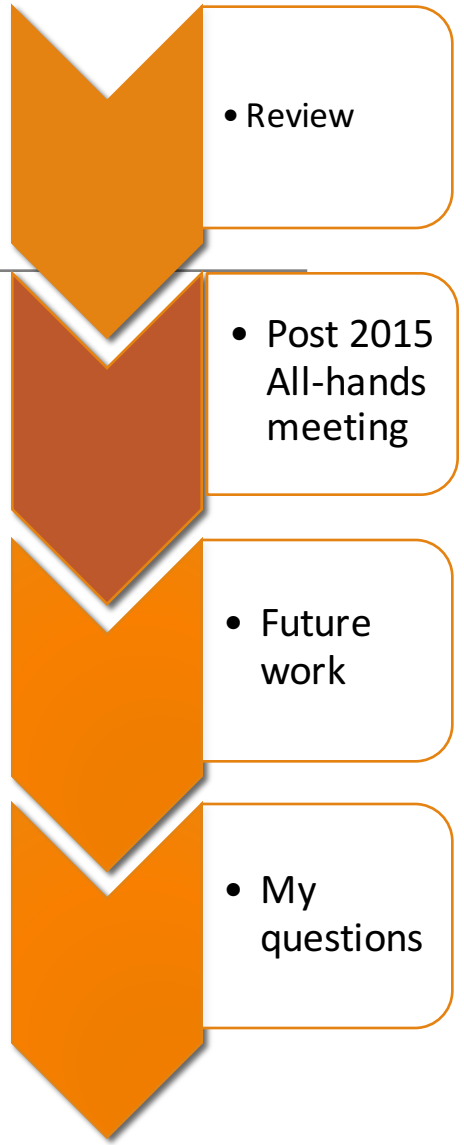
Underlying dynamics

- A perfect measurement of the current disturbances (coverage and sky brightness) is assumed.
- A perfect prediction of the coverage is assumed.



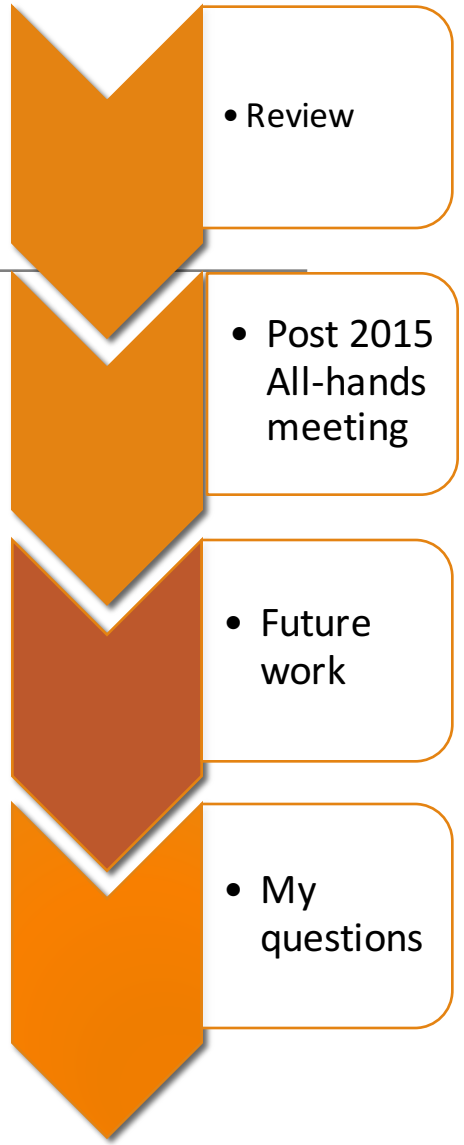
Implementation

- Piecewise constant features
  - $f_3(i,t)$:= altitude of the center of i'th field at t,
  - $f_4(i,t)$:= hour angle of the center of i'th field at t,
- SQLite output compatible for long term scheduling
- LSST-specific DE implementation
  - built-in vector optimization



(Near) Future work

- Improve approximations
  - Approximation 1: State space approximation
    - suggest a comprehensive feature pool and choose the best set of features
  - Approximation 2: Controller structure
    - implementation of the 2nd possibility design and compare to the 1st one
  - Approximation 3: Underlying dynamics
    - remove the assumption of perfect predictability
- Implementation
  - Input compatibility



My questions

1- Is there a unique and fixed partitioning of the sky and labeling of the fields in all simulations and datasets?

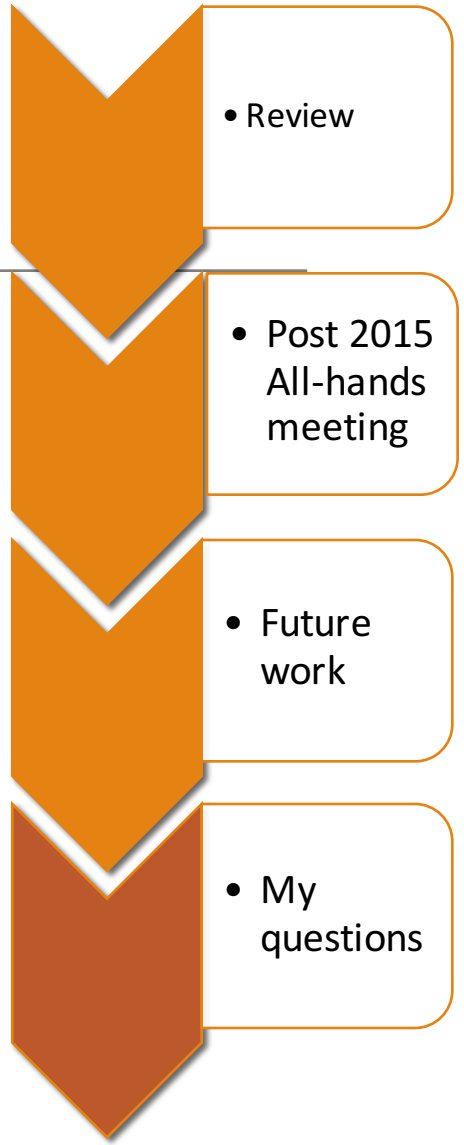
2- Can we substitute the air-mass constraint with an altitude threshold?

3- How to read OpSim SQLite Datasets, Tables of clouds and seeing?

4- How to decide a filter change?

5- What is the role of observation proposals?

6- What would be the best possible description of the temporary coverage?



Thank you