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(Towards) dynamical scheduling at CFHT

A wishlist and some ideas

Broad requirements

- Get “best return” feasible schedule (short term)
  - Maximize observation of high ranked programs
  - Respect observing constraints
  - Adapt to observing conditions
  - Adapt to new scheduling requests (e.g. TOOs, etc.)
- Optimize longer term goals: semester planning
  - Agency balance, completion rates, etc.
  - Specific time constraints
  - Dynamical adaptation of priorities cond. to past observations

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Static optimal queue generation

- Short term: next (few) night(s)
- Queues are generated before hand, assuming a given range of observing conditions
- OGs (local) scalar priorities are supposed given by a middle term optimization process
- OGs observation constraints are given (monitoring OGs, transits, etc.) or computed (airmass, distance to moon…)

The reservation concept

- Based on Lampoudi, Sanders & Eastman (2015) for the LCOGT telescope fleet
- Inspired from truck scheduling problems
- Associated to a given target/OG, necessary information for scheduling
  - d_i is a time duration of the observation
  - p_i is a scalar priority
  - t_i is a resource (e.g. a telescope, instrument…)
  - W_i is a list of "windows of opportunity", set of intervals where observation is possible and desired (intersection of constraints)
- Request of a project, with priority p_i, for exclusive access of resource t_i, for a contiguous interval of duration d_i, within one (or more) of the windows W_i

Discrete time parameters

- I = set of reservations
- T=set of slots (telescope id, time element or interval)
- S_i = set of possible starting slots for reservation i
- p_i = scalar priority of reservation i
- a_{ikt} = 1 if reservation i started at slot k will also use slot t
- d_{ij} is an time overhead to go from target i to target j
- b_{ijkt} =1 if transition (i,j) started at slot k will also use slot t

Integer Linear Programming formulation

- Decision variables: Y_{ik} = 1 if one starts reservation i at slot k, 0 otherwise
- Observations are done at most once
- Observations cannot overlap

OBJECTIVE FUNCTION

$$\hat{Y}_{ik} = \underset{Y_{ik}}{\operatorname{argmax}} \sum_{i \in I} \sum_{k \in S_i} p_i Y_{ik}$$

FEASABILITY CONSTRAINTS

- Observations scheduled at most once

$$\sum_{k} Y_{ik} \leq 1, \; \forall i \in I$$

- Observation should not overlap

$$\sum_{i \in I} \sum_{k \in S_i} Y_{ik} a_{ikt} \leq 1, \; \forall t \in T$$

More advanced constraints relating OGs

"One of" constraint: in a given group of observations, observe at most one

$$\sum_{i \in O_j} \sum_{k \in S_i} Y_{ik} \leq 1, \ \forall O_j \in O$$

AND constraints

$$\sum_{k \in S_i} Y_{ik} - \sum_{l \in S_j} Y_{jl} = 0, \ \forall (i,j) \in A_n, \ \forall A_n \in A$$

REELs: a particular combination of AND constraints !

$$Y_{ik} - \sum_{l \in W_{ijk}} Y_{jl} = 0, \ \forall k \in S_i, \ (i,j) \in R_{ij}, \ \forall R_{ij} \in R$$

$$\sum_{k \in S_i} Y_{ik} - \sum_{l \in S_j} Y_{jl} = 0, \ (i,j) \in R_{ij}, \ \forall R_{ij} \in R$$

Overheads

- Slewing overheads are not taken into account yet
- They depend on each pair of successive observations

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- Quadratic cost function
- Ignore impact on scheduling, valid if overheads << windows, texp…

$$\hat{Y}_{ik} = \underset{Y_{ik}}{\operatorname{argmax}} \sum_{i \in I} \sum_{k \in S_i} p_i Y_{ik} - \sum_{ik} \sum_{jl} Y_{ik} Y_{jl} C_{ij}^{kl} d_{ij}$$

C_{ij}^{kl} 1 if (i,j) are consecutive observations, 0 otherwise

d_{ij} overhead to slew from target i to target j

e.g. for contiguous observations:

$$C_{ij}^{kl} = a_{ikt} a_{jlt+1} \delta(t, k + d_i) \delta(l, t + 1)$$

Including overheads in time budget

$$\hat{Y}_{ik} = \underset{Y_i k}{\operatorname{argmax}} \sum_{ik} p_i Y_{ik} - \sum_{ik} \sum_{jl} \sum_{m} Y_{ik} Y_{jl} \delta(k, m - d_i) \delta(l, m + d_{ij}) d_{ij}$$

Account for overhead into time budget via quadratic constraint:

$$\sum_{ik} Y_{ik} a_{ikt} + \sum_{ik} \sum_{jl} \sum_{m} Y_{ik} Y_{jl} \delta(k, m - d_i) \delta(l, m + d_{ij}) b_{ijmt} \leq 1, \; \forall t \in T$$

where b_{ijmt}=1 if transitioning from i to j starts at slots m and still occupies slot t

(Mixed) Integer Quadratically Constrained Programming
MIQCP is offered by the Gurobi software

~~Mission Interministérielle pour la Qualité des Constructions Publiques~~

Soft constraints

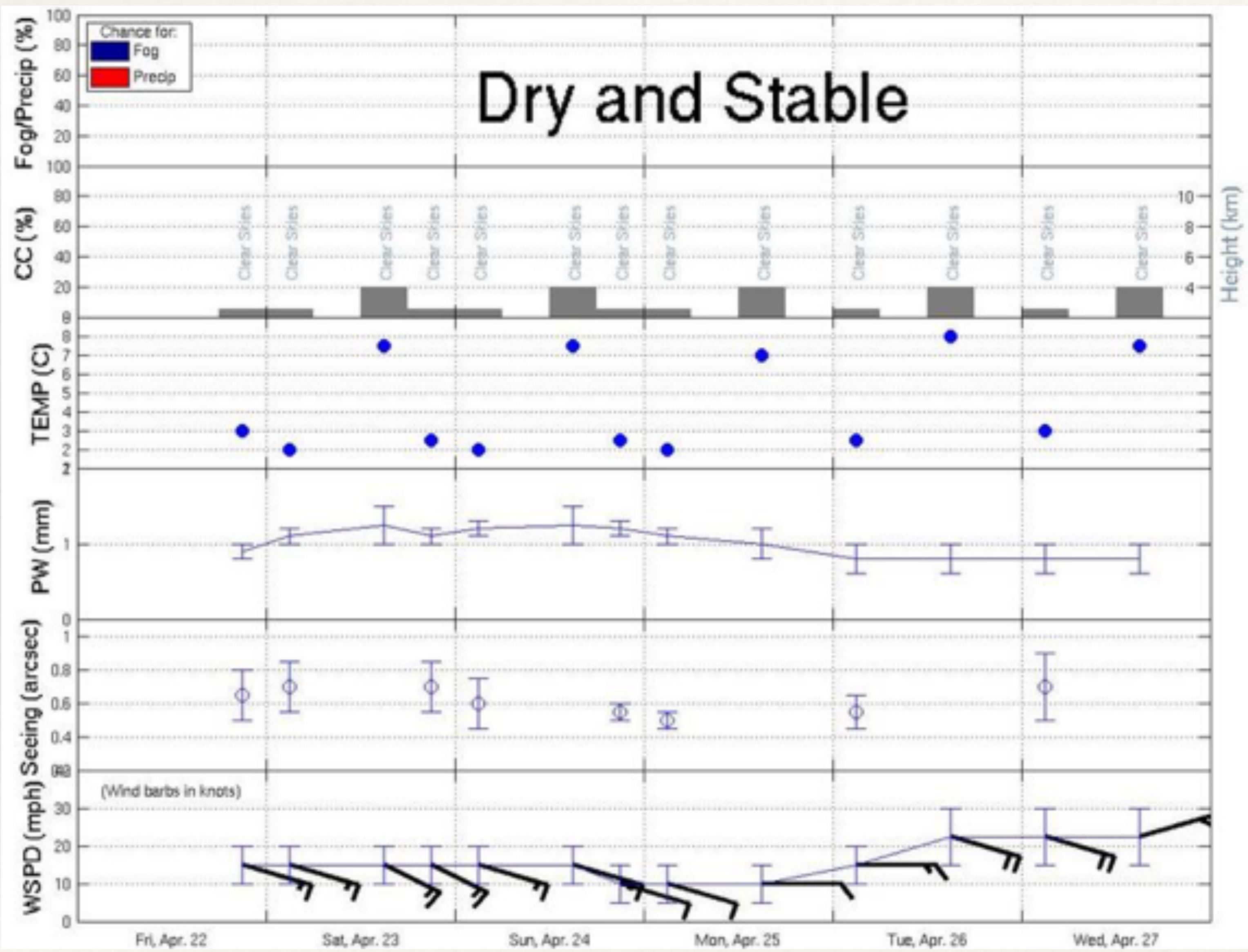
- Hard constraints in time (e.g. linked to airmass, hour angle, etc.) may be too constraining, and lead to suboptimal solution (holes in the queue…)
- Can be replaced by functions of diminishing return when a target is observed in conditions that are away from the optimal window
- In practice, it can be implemented by making the scalar priorities dependent on time: $p_i \Rightarrow p_{ik}$
- Same idea can be applied to twilight boundaries to ease scheduling if needed.

Getting dynamical…

- QSO-SNR: dynamical adjustment of exposure time conditionally to observing conditions, using either ETC (MP) or direct SNR estimate from exposure meter (ESPaDOnS). Needs to be coupled with dynamical scheduling !
- Run software at night before every new observation, or at least when conditions change substantially
- Use either a weather predictor (e.g. CFHT summit forecast), and/or a correlation length of weather states based on past weather data
- Integrate weather statistics/forecast into short and middle term scheduling… food for more thoughts.

the Maunakea weather center

Typical summit weather forecast chart



- 5 day forecast of
  - Temperature
  - Precipitation
  - Cloud coverage
  - Water pressure
  - Seeing
  - Wind speed & direction
- Large data base of past recordings could be used in complement to forecast, using a statistical model for short term variations

MKWC RMS	Night				
Variable	1	2	3	4	5
Temp	0.98	1.21	1.39	1.59	1.79
PW	1.35	1.52	1.59	1.82	2.01
Seeing	0.24	0.28	0.29	0.34	0.33

http://mkwc.ifa.hawaii.edu

Action needed !

- Develop prototype code in python using Gurobi MIQP solver (free license for academic sites) for a first static scheduling tool.
- Develop pre-processing functions of PH2 OG data into observability windows (ensemble of starting time slots) including all constraints. Needs API with new PH2 software.
- Test case: Spirou simulated catalog (C. Moutou), nice test bed with variety of target parameters.