ICKEP

Ground Based Astronomy Scheduling

Problem Specification

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1. Overview

This document describes the application program interface for the short term telescope scheduling problem for ICKEP. This problem employs SPIKE, developed by the Space Telescope Science Institute, as a simulator. The document first defines several terms used within, then covers the particulars of the time and Piecwise Continuous Function data formats used in the data files. Section 4 covers the inputs to your tool in the form of Observation, constraint and parameter definitions. Finally, section 5 describes the output format to be used by the simulator to evaluate your results.

2. Definitions

Assignment - The association of a task with a specific start time

Committed - A task that is scheduled.
Conflict - A constraint violation for a task
Constraint - A restriction of some sort between a set of tasks or on one task
Declination - Coordinate of an astronomical target, comparable to earth Latitude
Ignored - A task that is not a candidate for scheduling
PCF - A piecewise constant function representing values over time. For example, (time1 value1 time2 value2 ... timeN valueN) means <value1> holds from <time1> (inclusive) to <time2> (exclusive) ...
Right Ascension – Coordinate of an astronomical observation, comparable to earth Longitude
Suitability - A measure of goodness. Suitabilities are between 0-1. Higher values are better than lower values.
Task - An astronomical object which is to be scheduled
Universal Time – Or, Greenwich Mean Time, GMT.

Truncated Julian Date

The scheduling domain uses a modified version of Julian Date. Julian Date is the number of days since 12 noon, UT, January 1 4713 B.C. Because this number is large (millions), for precision's sake, a shortened version denoted as "Truncated Julian Date" was adopted for Spike (there are several others like this, including JDS and MJD) This time spec is similar in form to Julian Date, except the 0 is at Noon, May 6, 1979 (or, Julian date – 2444000) . For example, January 1st, 2007, midnight, UT = 10101.5 TJD. Assume all times in this document (and in the problems) are in TJD unless explicitly stated otherwise.

3. Ground Based Astronomy Background

Individual observation suitability for a ground based observatory can be affected by a variety of factors, including the positions of the Sun and Moon, the phase of the moon, the cloudiness of the night, and the angle of the observed target at a given time. For our purposes, our initial problems will be limited to considering the combination of the airmass (angle) and sun factors (ignoring, primarily, the moon).

Airmass

The Airmass suitability refers to the suitability of observing a target based on how much of the atmosphere its light must travel through to reach the telescope. Thus, the best angle for viewing a target is 90 degreess, straight above the telescope, known as the Zenith. The airmass suitability is, for our problem, calculated based on the zenith angle of the observation (the angle between the zenith and the target) which is then rated based on an input table (meridian-suitability-map in input parms).

The coordinate system used in this simulation assumes fixed coordinates for astronomical targets; the center of the Earth is at the origin of this coordinate system, and the Earth moves in this fixed coordinate system. We'll illustrate calculating the Zenith Angle using an Observatory on Mauna Kea (Lat 19.8285, Long 204.52) viewing Betelgeuse (RA 88.79, DEC 7.41) in the following discussion.

Zenith angle of (RA, DEC, Time, Observatory) = (acos (o1 • p1))

Where the (unit) Observatory positon vector o1 is the cartesian vector through the observatory at

LONG = observatory longitude + Greenwich Mean Sidereal Time of Time

LAT = observatory latitude.

To calculate GMST from Time (in TJD): Let T0 be the time of interest. Let F be the fractional portion of the Julian date elapsed since the previous midnight (0h) UT, thus:
F = T0 - (floor(T0)) + 0.5

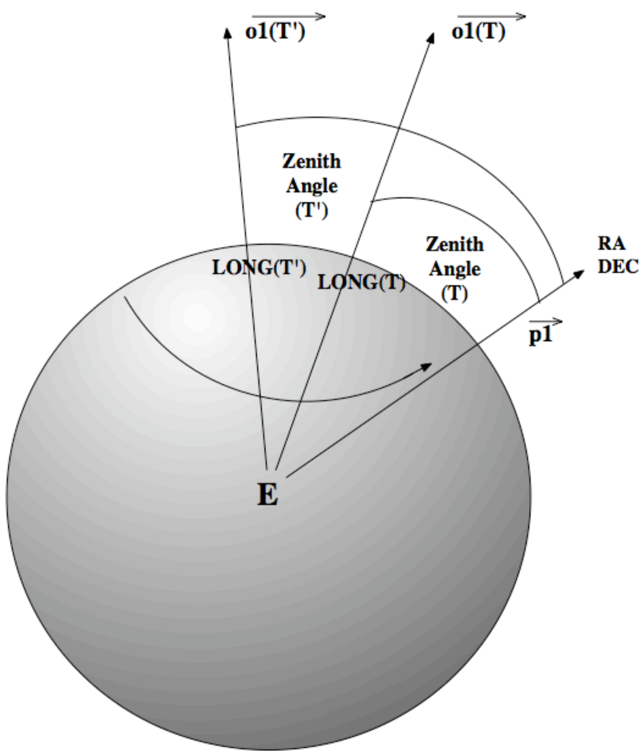
Now compute the fractional number of centuries, D, from 1900 January 1, 12h UT, Truncated Julian date
T=28980.0 (Number of days to add to T0 to get days since 1900).
D = (T0 + T) /36535

P = 0.276919398148148148 + 100.00213590277777 D + (1.0752314814814815*10^-6)(D^2)
Then the Greenwich mean sidereal time in Radians is
GMST = 2pi * ((P + F) Modulo 1)

We get the vector o1 from:

o1 = ((cos LAT) * (cos LONG), (cos LAT) * (sin LONG), (sin LAT))

As we see, o1 changes over time due to the rotation of the Earth and its impact on LONG; this is shown graphically in the figure below.



For example, on Mauna Kea at TJD 10000.0:

Latitude 19.8285 Longitude 204.52 – in radians, 0.3461 3.5695. Converted by adding Greenwich Mean Sidereal Time of 3.1455 radians for TJD 10000.0 to the longitude, we have LAT=0.3461, LONG=6.7150. Thus the vector o1 is: (0.8543 0.3938 0.3392)

Position-vector p1 for the target RA DEC is a unit vector to the target – taken from RA and DEC (after converting to radians):

p1 = ((cos RA) * (cos DEC), (cos RA) * (sin DEC), (sin RA))

For example, Betelgeuse (RA 88.79 DEC 7.41, in radians, 1.5497, 0.1293):

Unit vector p1 is: (0.0209 0.9914 0.1289)

The angular separation between the viewer vector and the target vector is calculated by: (acos (o1 • p1)), (maxed at Pi if (o1 • p1) is <-1 or 0 if > 1).

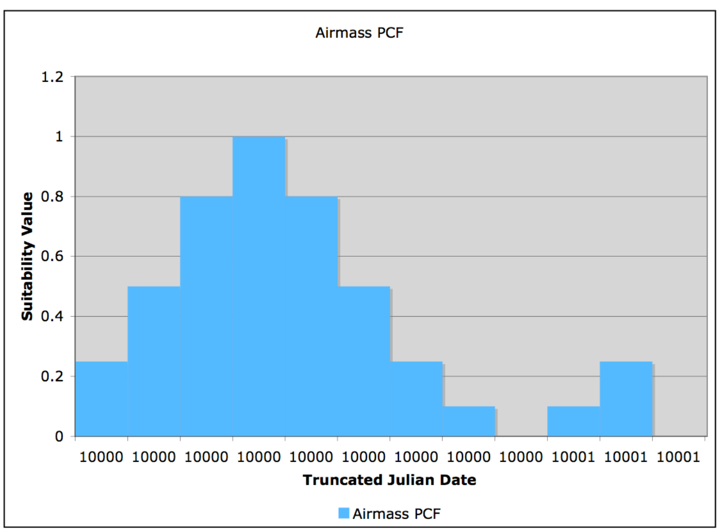
Thus, for our example, the Zenith Angle (in radians) at TJD 10000.0 is then:

Acos((0.8543 0.3938 0.3392) • (0.0209 0.9914 0.1289)) = acos(0.4520) = 1.1018

Which is 63.1284 degrees. Using the input "meridian-suitability-map" of (0 1 31 0.8 46 0.5 61 0.25 71 0.1 89 0), observing Betelgeuse at TJD 10000.0 would then be valued at 0.25 "suitability" in the lookup table (as the Zenith Angle is between 61 and 71).

For the day from TJD 10000.0 to 10001.0, the suitability of observing Betelgeuse from our hypothetical telescope on Mauna Kea, expresssed as a PCF for just the "airmass" would be:

(10000.0 0.25 10000.006305809047 0.5 10000.050695837639 0.8 10000.096348485215 1 10000.258547543586 0.8 10000.30408698987 0.5 10000.348548121632 0.25 10000.378007645704 0.1 10000.431211586707 0 10000.920895681134 0.1 10000.974106316266 0.25 10001.0 0) Visually, the PCF looks like this:



Sun

The Sun component of the suitability of viewing an observation is calculated in a very similar manner to the Airmass. The difference is that the zenith angle of the Sun itself must be calculated over time, and if it is **less** than the input angle (sun-twilight-angle, in the input parameters), the observation may not be viewed at that time. The zenith angle calculation is the same as that for other targets, except the Sun is a (rapidly) moving target. Calculating the position vector of the

Sun is thus a more complex calculation. First we need to define several constants, given that we are calculating based on Epoch 1980:

T0 = Time of interest, in TJD.
T = 28980 (as above, # days to shift T0 to get days since 1900)
ε (Ecliptic longitude of the sun at epoch): 4.86656333799131
ϖ (Ecliptic longitude of the sun at perigee): 4.9322376866427815
e (Eccentricity of the sun): 0.016718
R: 238.5 (number of days to subtract from TJD to get days to 1980 reference epoch)
P (Period of the Sun): 365.2422
2PI: 6.283185307179586

The position vector of the Sun is calculated based on the obliquity of the ecliptic plane, and the ecliptic longitude, ε, of the Sun.

O (Obliquity of the ecliptic) = 23d27'08 - 46.8 * D
using D, the number of centuries since 1900, which is ((T0 + T) / 36525).
Or, in radians and TJD:
O = 0.40931849468715903 – (0.00022689280375926285 * (((T0 +T) / 36525)))

ε can be obtained using the equation:

ε = (V + ϖ) Modulo 2pi

The complex part of the calculation is the True Anomaly, V. First we calculate the Mean Anomaly, M. The mean anomaly can then used to find (a good approximation for) V. M is calculated as follows:

M = (N + ε - ϖ) Modulo 2pi

Where N = ((2pi * (TJD – R)) / P) Modulo 2pi.

From M, we can calculate the Eccentric Anomaly E, as defined by Kepler’s Equation:
E – e sin(E) = M

This equation is complex, but can be approximated using iterative methods. For example, see routine R2 in Duffet-Smith, pg. 90.

Having found E, the True Anomaly, V, is then:
Tan(V/2) = Sqrt((1 + e) / (1 - e)) Tan(E/2).

Then, as mentioned above, ε = (V + ϖ) Modulo 2pi.

Given O and ε, the position vector s1 of the Sun is calculated with the following linear combination:

v1 = (1 0 0)
v2 = (1 (cos O) (sin O))
s1 = (cos ε) v1 + (sin ε)v2.

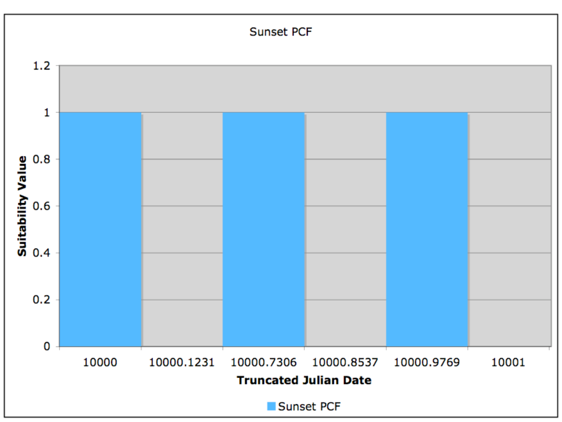
Finally, as in the airmass calculation, we find the angular separation θ between s1 and o1:

θ = (acos (o1 • p1)). (in radians).

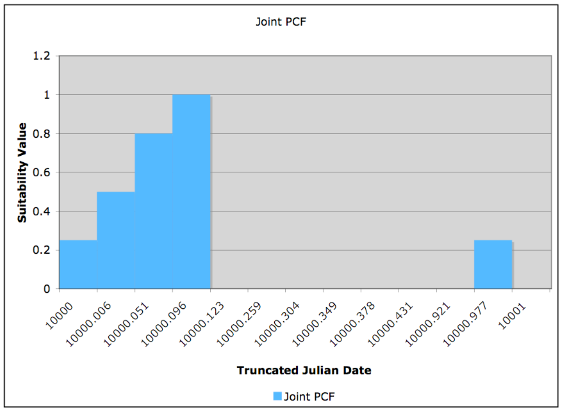
Finally, we convert this to degrees, and compare with the sun twilight angle.

Example:
T0 = 10000.0 (TJD)
O = 0.4093 – (((10000.0 +28980) / 36525) * 0.000226892803759262 85)
= 0.4090763514578214
N = ((2pi * (10000.0 – 238.5)) / 365.2422) Modulo 2pi = 4.562228396343254
M = (4.562228396343254 + 4.866563337991 31 - 4.9322376866427815) Modulo 2pi
= 4.496554047691782
4.496554047691782 = E – e sin(E). Solved, E = 4.480284350380767
V = -1.8191402066716884
ε = (-1.8191402066716884 + 4.9322376866427815) Modulo 2pi
= 3.113097479971093

s1 = (cos ε) v1 + (sin ε)v2
= (cos 3.113097479971093) (1 0 0) +
(sin 3.113097479971093) (1 0.9174886064788763 0.39776206076176945))
= (-0.9995940400104462 0.026140459233437364 0.011332765181526492)
θ = (acos (o1 • p1)) = (acos -0.8398547700241537) = 2.567811942200735
= 147.124786871393 degrees.
Thus, at TJD 10000.0, the Sun is below the twilight angle, and the suitability, with regards to the Sun, of viewing at this time is good. Starting on TJD 10000.0, the Sun suitability PCF is:
(10000 1 10000.123145706717 0 10000.73058347138 1 …)



If we combine the sunset PCF and the airmass suitability PCF, we get a combined preference function for this observation that looks like this:



4. Generic Specifications for Interface Functions

The following specifications will be referred to throughout the document.

Time Specification <TIME-SPEC>

Times are specified as follows. The time is specified in Universal Time.

(yr mon day hr min sec ms)

yr	- 4 digit number representing the year (i.e., 1996)
mon	- number representing the month (i.e., 1-12)
day	- number representing day of month (ie., 1-31)
hr	- number representing the hour (ie., 0-23)
min	- number representing the minute (ie., 0-59)
sec	- number representing the second (ie., 0-59)
ms	- number of milliseconds (ie., 0-1000) - optional argument - defaults to 0

PCF Specification <PCF-SPEC>

Specifies how a function (ie.,values) change over time. Value could be preference, conflicts, resource, etc.

Format -> (t1 v1 t2 vl2 ... tN vN)

t1-tN are times. See <Time-Spec> definition

v1-vN are values. Units depend on value

This says that the function takes on value v1 between t1 (inclusive) and t2 (exclusive), v2 between t2 (inclusive) and t2(exclusive), etc.

5. Problem Specification Formats

This section describes the required interface for the problem specification.

Task & Constraint Definition

This section describes the input forms for the task and task constraints.

Tasks

(DEF-OBS-BLOCK :name :program-id :ra :dec :task-duration :priority :telescope :instrument :mode :setup-time :meridian-suitability-map)

ARG Descriptions:

- name - a string which names the task, required arg
- program-id - a string which identifies the program id, required arg
- ra - right ascension of target for task (J2000), degrees, required arg
- dec - declination of target for task (J2000), degrees, required arg
- task-duration - duration of the task in seconds, greater than 0, required arg
- priority - priority of task, lower numbers mean higher priority, positive nums, required arg
- telescope - string naming the telescope that is needed, required arg
- instrument - string describing the instrument used, required arg
- mode - string describing the mode used or a list of strings describing the modes used by the observation. If a single string, then the observation is assumed to use only one mode and overheads will be calculated using the mode supplied. If a list is supplied, Spike assumes that the first mode in the list is used at the beginning of the observation and the last mode in the list is used at the end of the observation. All modes supplied in between the first and last in the list are ignored. The first mode is used to calulate overheads before the observation is executed. The last mode is used to calculate overheads after the observation is executed.
- sun-twilight-angle - If the angle separation between the meridian and the sun is less than this value, then the sun is up and the sun suitability is 0. Angle in degrees. Default is nil. If non-nil, overrides the global setting from DEF-ST-SCHEDULER-PARAMETERS. If not supplied, the global default is used.
- setup-time -overhead associated with task in seconds. Default is 0
- meridian-suitability-map - table that maps angular separation between the meridian and the line of sight of the target to suitability values. A PCF. Values are suitabilities between 0.0 and 1.0. What usually is time is the angular separation in degrees. If this value is supplied, then it is applied to this obs block only and overrides the defaults specified in the DEF-ST-SCHEDULER-PARAMETERS form. If not supplied, the global default is used.

DOCUMENTATION

Defines one observation.

(DEF-INTERNAL-CALIBRATION-OBS-BLOCK :name :program-id :task-duration :priority :telescope :instrument :mode :(setup-time 0) : (viewing-time "night"))

ARGS:

name	- a string which names the task
program-id	- a string which names the program
task-duration	- duration of the task in seconds
priority	- priority of task, lower numbers mean higher priority, positive nums
telescope	- string naming the telescope that is needed
instrument	- string describing the instrument used
mode	- either a string -> instrument mode used by task, or a list of strings representing the first...last mode used by the observation.
setup-time	- overhead associated with task in seconds. Default 0
viewing-time	- one of 'night' 'day', 'all-time'. Default 'night'. restricts when the calibration can be taken

DOCUMENTATION:

Defines one internal calibration observation. Such a calibrator merely needs to be performed at some point during the plan in order for the plan to be valid. Internal calibrations may ignore Sun and Moon constraints.

Constraints

(DEF-ORDER task1 task2)

ARGS:

task1	- a string which names task1
task2	- a string which names task2

DOCUMENTATION

task1 is before task2

(DEF-ORDER-AND-OFFSET task1 task2 offset)

ARGS:

task1	- a string which names task1
task2	- a string which names task2
offset	- minimum end to start separation between task1 & task2 in days

DOCUMENTATION

task1 is before task2 by offset

(DEF-GROUP-WITHIN time tasks)

ARGS:

time	- all tasks within this time in days
tasks	- list of tasks, where each task is a string ->(“tn1” ... “tnN”)

DOCUMENTATION

All tasks should be grouped within the specified time

(DEF-START-WITHIN time task1task2)

ARGS:

time - separation between task1 & task2 in days

task1 - a string which names task1

task2 - a string which names task2

DOCUMENTATION:

Start of task1 precedes start of task2, or follows end of task2 by this time in days

(DEF-MIN-TIME-SEPARATION task1 task2 min-time)

ARGS:

task1 - a string which names task1

task2 - a string which names task2

min-time - minimum time separation between task1 & task2 in days

DOCUMENTATION

task1 and task2 should be separated by a minimum of min-time

(DEF-WINDOW early-start late-start task preference)

ARGS:

early-start - earliest time the task can start. See <TIME-SPEC> above.

late-start - latest time the task can start. See <TIME-SPEC> above.

Task - a string which names task

preference - a preference for this window. Number between 0 and 1.0

DOCUMENTATION:

task should start between early-start and late-start with preference. So we could say schedule task between early-start and late-start with preference. The total window definition is the intersection of all the DEF-WINDOW forms.

(DEF-PHASE start-time period phase-min phase-max task)

ARGS:

start-time - time when the periodic phenomena starts. See <TIME-SPEC> above.

Period - period of the phenomena in days

phase-min - start point in the period that you are interested in number between 0 and 1. Percent of period

phase-max - end point in the period that you are interested in number between 0 and 1. Percent of period

task - a string which names the task

DOCUMENTATION

Defines a periodic phenomena for task and what part of the period (ie., phase) the task is interested in observing.

(DEF-ABS-ZENITH-ANGLE-RANGE task1 zenith-low zenith-high)

"ARGS:

task1 - a string which names task1

zenith-low - Low zenith angle input

zenith-high - High zenith angle input

DOCUMENTATION:

task1 should be sceheduled such that its angle from the zenith when scheduled is between zenith-low and zenith-high"

(DEF-MAX-ZENITH-ANGLE-SEPARATION task1 task2 max- zenith)
ARGS:
task1 - a string which names task1
task2 - a string which names task2
max-zenith - maximum zenith angle separation between task1 & task2 in degrees
DOCUMENTATION:
task1 and task2 should be sceheduled such that a maximum of max-zenith degrees separates their respective angles from the zenith when scheduled

Global Scheduler Parameters

(DEF-ST-SCHEDULER-PARAMETERS :sched-start :sched-end :time-quantum :sun-twilight-angle :meridian-steps :meridian-steps :meridian-suitability-map)
ARG Descriptions:
sched-start - start time for the scheduler. See <TIME-SPEC> above. required arg
sched-end - end time for the scheduler. See <TIME-SPEC> above. required arg
time-quantum - the time discretization interval for the scheduler in days.
sun-twilight-angle - if the angle separation between the meridian and the sun is less than this value, then the sun is up and the sun suitability is 0. Angle is degrees Default is 108.
meridian-steps - then number of sampling steps between sched-start & sched-end used in calculating the angles between the meridian and sun, moon, and target. Default is 100
meridian-suitability-map - table that maps angular separation between the meridian and the line of sight of the target to suitability values. A PCF. Values are suitabilities between 0.0 and 1.0. What usually is time is the angular separation in degrees. Default is '(0 1.0 31 0.8 46 0.5 61 0.25 71 0.1 76 0)
DOCUMENTATION:
Defines a set of global scheduler parameters for the short term scheduler
(DEF-TELESCOPE-PARAMETERS :name :longitude :latitude :altitude)
ARG Definitions:
Name - telescope name -> string. required arg
Longitude - geographic longitude in degrees, 0 to 360, measured EASTWARD. required arg.
latitude - geographic latitude in degrees ,-90 to 90. required arg
altitude - altitude in meters above sea level, must be between -100 and 10000 meters. required arg
max-speed - maximum speed of the telescope in degrees/sec
acceleration - acceleration of the telescope in degrees/sec2
DOCUMENTATION:
Defines a set of global telescope parameters

6. Result Format

This section defines the input format for the scheduling engine simulator, and thus the output that can be accepted for competitor's results.

(SCHEDULE-NAME "name")

(LOCKED <list of locked observations>)

(IGNORED <list of ignored observations>)

(COMMITTED <list of observation assignments in the form:

  (<observation name (from input)> <assigned-time in TJD>)

)

For the purposes of this simulation, LOCKED may not be of use, but IGNORED may be desired to declare, explicitly, that the planner/scheduler decided to schedule around/without that observation.

Example:

```
;; schedule-name:
(SCHEDULE-NAME "ICKEP")

;; locked:
(LOCKED
 )

;; ignored:
(IGNORED
 )

;; committed (assigned):
(COMMITTED
 (L1551              9000.0639)
 (HUBBLE_DEEP_FIELD    9000.0958)
 (SUBARU_DEEP_FIELD    9000.0104)
 (SDSSP_J003525.29+004002.8 8999.7826)
 (PSS                8999.7944)
 (PC                 8999.7736)
 (SDSSP_J015339.61-001104.9 8999.7222)
 (SDSSP_J021102.72-000910.3 8999.7431)
 (FS1                8999.9167)
 )
```