Telescope Time Allocation Tool

TaToo is ESO's new Time Allocation Tool. This software scheduler is a combination of a user-friendly graphical user interface and an intelligent constraint-programming engine fine-tuned to ESO's scheduling problem. TaToo is able to produce a high quality and reliable schedule taking into consideration all constraints of the recommended programs for all telescopes in about 15 minutes. This performance allows schedulers at ESO-VISAS to simulate and evaluate different scenarios, optimize the scheduling of engineering activities at the observatories, and in the end construct the most science efficient schedule possible.

João Alves, European Southern Observatory

Every six months about 900 scientific observing proposals are written to make use of ESO telescopes. Proposals are evaluated by an external Observing Programmes Committee (OPC), which recommends the allocation of telescope time via a ranked list of proposals (see Figure 1). The goal of the Time allocation Tool (*TaToo*) is to schedule the telescopes in the most optimal and reliable manner possible, taking into consideration the full set of constraints of each OPC recommended observing program. *TaToo* is not intended to be a fully automated "black-box" program, but a user friendly, interactive, semi-automated tool used by ESO's Visiting Astronomers Section (VISAS) to generate and maintain the long-term scheduling of ESO telescopes.

Today, after successfully scheduling the last two observing semesters with *TaToo*, we must take a step aside to pay tribute to the fomer Head of VISAS, Dr. Jacques Breysacher, who scheduled ESO's telescopes for almost 30 years (see Figure 2). Dr. Breysacher was the initiator and the strongest supporter of the *TaToo* project and perhaps the only one who can fully appreciate the intricacies of an automated scheduler for ESO telescopes. His experience and strong sense for practical solutions were fundamental during the development of *TaToo*.

Our approach to the scheduling technology

The challenge to develop a software tool with a high production quality has forced us to make a very careful choice of the underlying scheduling technology. The reliability of this tool and the quality of the schedule produced are of paramount importance to the observatory. A schedule solution that secures optimal observing conditions for each recommended program and maximizes the number of programs on the telescopes contributes decisively to the effective usage of ESO telescopes, boosting the scientific return of the observatory.

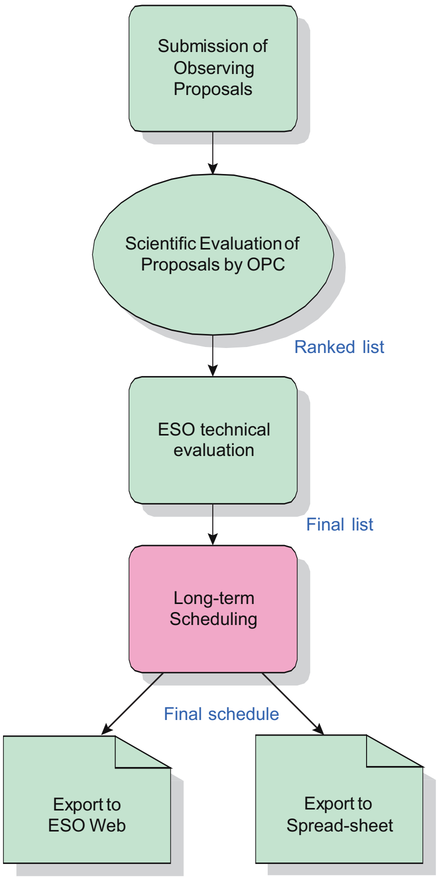
At the beginning of *TaToo*'s design, in 2003, we did an extensive evaluation of the existent telescope scheduling systems. Among the different systems were 1) Spike by Johnston and Miller (1996), 2) the system by Grim et al. (2002) based on a genetic algorithms scheduler, 3) the "Just-in case" telescope scheduling algorithm developed by Drummond et al. (1994), etc. Of all of these, only Spike was an established telescope scheduling system that due to its modular constraint satisfaction solver was flexible enough and could potentially be adapted for use at ESO. An attempt to adapt Spike at ESO is described by Giannone et al. (2000). However, the design of the Spike scheduler had been done in the early 1990s, at a time when constraint programming was still at its early stages of development. Contemporary constraint programming systems include a large number of very powerful search and constraint propagation techniques that offer more effective scheduling, see, e.g., Baptiste et al. (2001).

This conclusion, as well as a careful study of the available open-source/commercial optimization and scheduling technology, allowed us to define our approach to the development of *TaToo* as follow: "Select a modern and real-life proven scheduling technology, and focus efforts on the interface with the ESO scheduling problem". It was quite clear from the beginning of the project that developing a new scheduling technology from scratch was beyond the scope and budget of the project. Instead, most of the one year we had to complete the project would have to be spent translating the ESO scheduling problem to the language of a well-established scheduling technology.

During our search for the best scheduling technology on the market we analyzed systems based on:

- Genetic algorithms: i2 (2002).
- Linear, quadratic and integer optimization systems: Optimization Solutions Library – IBM, see COIN (2002); Xpress – Dash Optimization (2002), CPLEX – ILOG (2002).

Figure 1: The workflow of the long-term scheduling process at ESO: For each 6-month semester a large number (currently about 900) of observing proposals are submitted to ESO. The independent Observing Programmes Committee (OPC) evaluates all proposals and recommends time allocation by creating a ranked list where the proposals are ordered according to their scientific merit. The technical feasibility of the proposals is checked during the ESO's technical evaluation. The final list (OPC ranked) is then used by VISAS as input to the long-term scheduling. The final schedule is stored in an ESO database and published in web and spreadsheet forms.



- Constraint programming: CHIP V5 – COSYTEC (2002); clp(fd) – Diaz (2002) and IC-Parc (2002), open source; Solver/Scheduler – ILOG (2002); Mozart/Oz (2003) – DFKI, open source; Koalog Constraint Solver (2003).

In order to experiment with the different algorithms and modeling strategies, and to evaluate performance, we developed a prototype of *TaToo*. Finally, after comparison between a complete set of results, we selected the combination Solver/Scheduler of the French company ILOG. The Solver is a library for constraint programming while the Scheduler sets an additional abstraction layer over the Solver that simplifies and optimizes the modeling through notions like activities, resources, reservoirs, states, precedences, etc. These two libraries are being used by many organizations like Deutsche Bahn, SAP, Lufthansa, Daimler Chrysler, Deutsche Telekom, BMW, Nippon Steel, NFL, IBM, Metro de Madrid, etc. – see Connection (2003).

The software package of ILOG contains an Integrated Development Environment (IDE) with debugging functions that we used extensively during the development of scheduling models and defining optimal search strategies (Figure 3).

TATOO'S ARCHITECTURE

The architecture *TaToo* is shown in Figure 4. The entire scheduling and control logic is hosted on the Scheduling Server. The data are stored in two databases on the Database Server(s). The clients access the system through a (fat client) graphical user interface (GUI).

Each observing program sets a range of requirements and conditions on the scheduling. The Control Logic reads them from the Observing Proposals database and transfers them to the Scheduling Engine. There, proper constraints are generated and sent to the Solver/Scheduler together with the corresponding constraint Models. The scheduling results are written back to the Operational Data database. The system operator has access to all relevant data and control over the entire scheduling process via the GUI Client (Figure 5 and Figure 6). The Models are written in Optimization Programming Language (OPL), the Control Logic and the Scheduling Engine in Perl, the GUI Client in Java. The libraries Solver/Scheduler are precompiled (written by ILOG in C++).

HOW DOES TATOO SCHEDULE?

There are two modes of scientific observations at ESO telescopes: the Visitor mode (VM) and the Service mode (SM). VM is the classical mode of observations in which the observations are executed by an astronomer from the proposing team that is physically present at the telescope. SM observations, on the other hand, are performed by the ESO observatory staff. VM observations consist of runs; a run may be additionally divided into

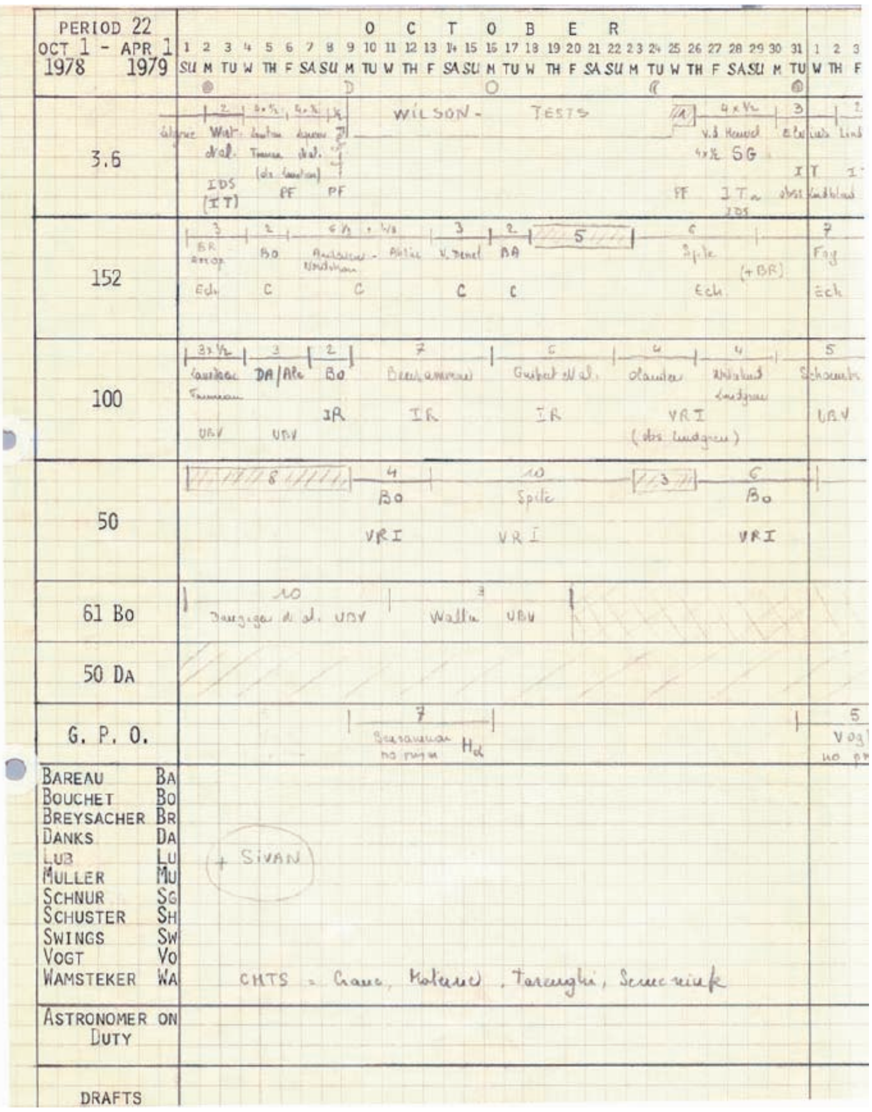
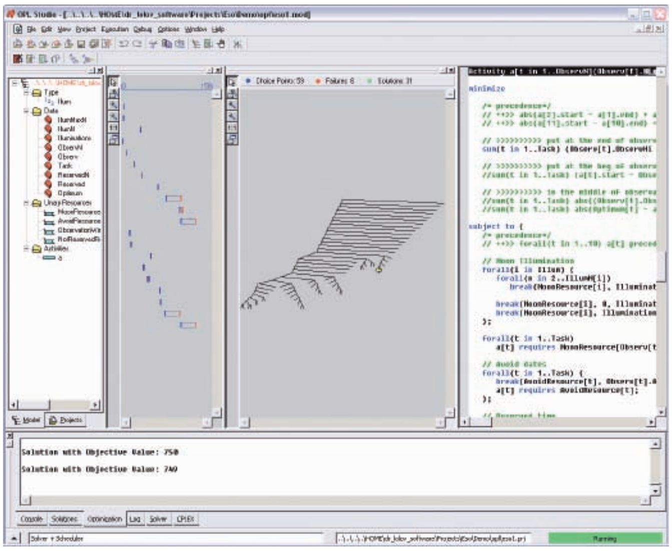


Figure 2: First ESO telescope schedule computed by Dr. Jacques Breysacher, for Period 22 (1978). The know-how accumulated during almost 30 years of scheduling ESO telescopes was fundamental in the translation of the ESO scheduling problem to scheduling technology language.



```
minimize

subject to {

   forall(i in Illum) {
      forall(m in 2..IllumN[i])
         break(MoonResource[i], Illuminat

      break(MoonResource[i], 0, Illuminat
      break(MoonResource[i], Illumination
   };

   forall(t in 1..Task)
      a[t] requires MoonResource[Observ[t

   forall(t in 1..Task) {
      break[AvoidResource[t], Observ[t].A
      a[t] requires AvoidResource[t];
   };
```

```
Solution with Objective Value: 750

Solution with Objective Value: 749
```

Figure 3: The OPL Studio of ILOG used for the development of the Constraint Programming models of *TaToo*. The panels show (from right to the left) the source code of the OPL (Optimization Programming Language) model; the solution search tree; the earliest/latest time spans of each variable; the data structure of the model. The lower panel shows the progress of the optimization.

sub-runs. A sub-run is the smallest schedulable entity and occupies at least half a night (Figure 7). SM observations, on the other hand, are performed in one-hour observation blocks.

From *TaToo*'s perspective, the substantial difference between VM and SM observations is the search space in which the scheduling takes place. The VM (sub)runs are scheduled on the time axis, meaning that each scheduled VM run becomes a particular, fixed time span for execution. The SM runs are scheduled in a "resources" space. A scheduled SM run is one that has been accepted in the schedule if sufficient resources for its execution are available. The observatory staff determines when a scheduled SM run will be performed after considering the meteorological conditions, the current states of the queues, and its chance of getting substantially completed by the end of the observing semester.

TaToo schedules VM runs by proper OPL models. The models take into account all parameters important for the run like OPC-ranking, object coordinates, required moon illumination, sub-runs configuration, angular distance to the moon, critical and avoid-dates, etc. (Figure 8 and Figure 9). These parameters are used to generate the corresponding constraints of the models. In some cases, e.g., to minimize the number of instrument changes, the models themselves define additional constraints at run time. The effective algorithms for constraint propagation implemented in Solver/Scheduler libraries as well as the properly selected search strategies in the models lead to very good scheduling performance. On a 2 GHz single processor computer the scheduling of all seven telescopes takes less than 15 minutes. In this time ≈ 100.000 constraints and 500–1000 sub-runs per telescope are evaluated and (some of them) scheduled.

For the scheduling of SM observations *TaToo* implements a two-step procedure:

Step 1: On this step *TaToo* generates the so-called pseudo-VM (PVM) runs. The generation works in the following way. The RA coordinate of each target of each requested SM run is used to define a visibility window where the target can potentially be observed. A new PVM run is defined for that target, including the required moon illumination as a constraint. To compensate the different time resolution of VM (0.5 nights) and SM (1 hour) a procedure fills-up the 0.5 night block in PVM by adding other relevant targets of the same SM run or of rank-neighboring SM runs.

Depending on the VM/SM time distribution and on the particular SM pressure at each telescope, a large number of interchangeable PVMs may be generated. A special procedure analyzes the configuration of the generated PVMs and removes the logical symmetries by generating sets of additional precedence constraints. This substantially prunes

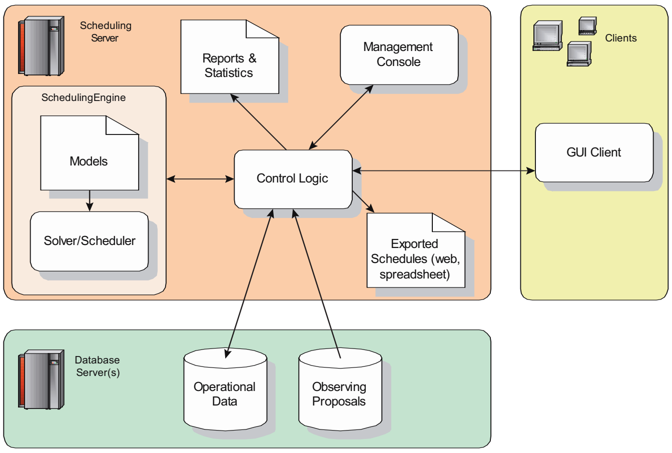


Figure 4: Architecture of *TaToo*.

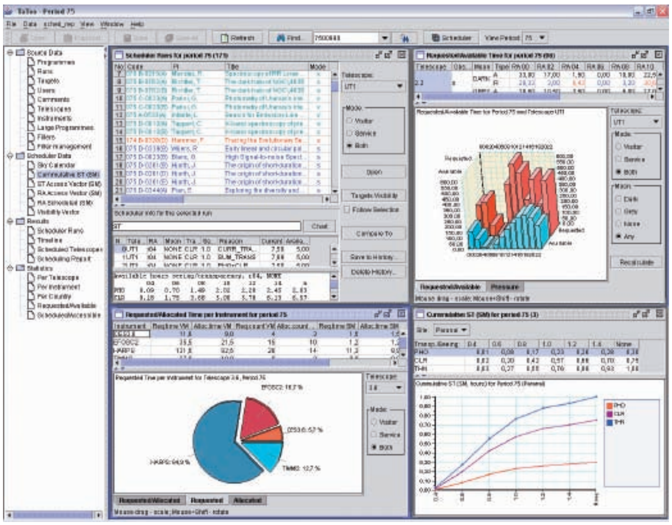


Figure 5: At any point of the scheduling process the graphical user interface of *TaToo* provides access and control of all relevant for the scheduling data.

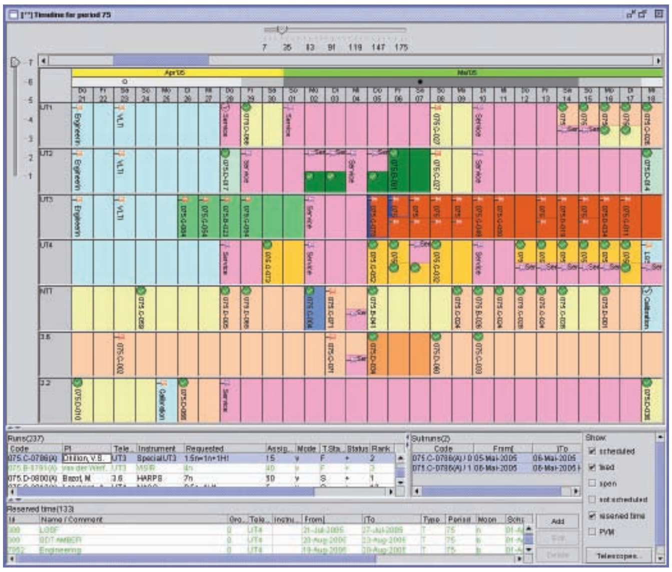


Figure 6: Graphical presentation of the final schedule in a timetable form. The instruments are color-coded. The pink color denotes time allocated for SM runs. The panes with tables below the timetable provide detailed information about each scheduled run.

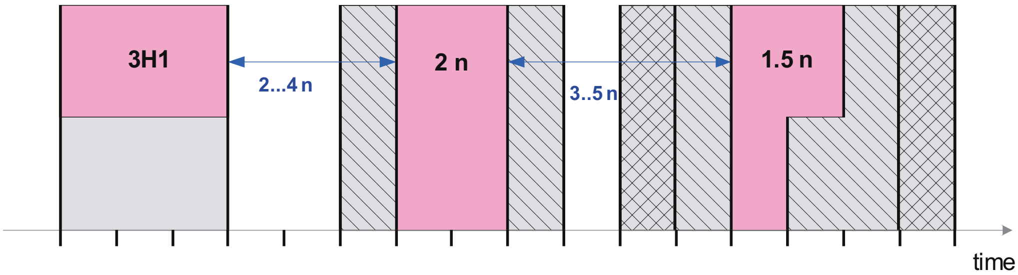


Figure 7: The VM run shown here consists of 5 sub-runs. The “3H1” are three first half-nights, followed by “2n” – two whole nights and “1.5n” – 1.5 nights starting at the beginning of a night. The required intervals the sub-runs are 3 nights ± 50% between sub-runs “3H1” and “2n” and 4 nights ± 50% between sub-runs “2n” and “1.5n”. The diagonally-striped gray areas show the areas where sub-runs “2n” and “1.5n” may be scheduled, provided sub-run “3H1”is on a fixed position. Actually, *TaToo* tries to find optimal positions of all three sub-runs simultaneously by introducing from- and to-limits of the distance constraints.

the search tree and increases the overall scheduling performance.

Finally, the PVMs are competitively mixed with the VM (sub)runs by taking into account the OPC ranking list (Figure 10) and are fed to the OPL models for scheduling.

Step 2: During this step of the SM scheduling *TaToo* implements an algorithm based on the ones described in Silva (2001). The algorithm uses a RA/MOON/SEE/TRANS (RMST) model and schedules by consumption of time resources. The calculation of the available time resources is based on statistical data about the weather conditions at the observatories’ sites and is performed for the time spans of the PVM runs scheduled during Step 1.

The described SM scheduling procedure provides a fair time assignment, especially in the over-subscribed RA-ranges (see Alves & Lombardi 2004) as it leverages the advantages of both the constraint programming models and the RMST model.

FINAL REMARKS

One of the most important characteristics of *TaToo* is its overall performance. *TaToo* is able to produce a high quality and reliable schedule taking into consideration all constraints of the recommended programs for all telescopes in about 15 minutes. This is crucial for a final optimization level where the *TaToo* operator, an astronomer, can simulate and evaluate different scenarios (e.g., further diffusing oversubscribed RA’s, assessing the impact of an unpredictable instrument failure, etc.) in more or less real time. These simulations also allow for an optimal long-term scheduling of large engineering time blocks (small engineering time blocks and instrument calibrations are automatically scheduled by *TaToo*), enabling the ESO schedulers to construct the most science-efficient schedule possible.

Finally, users must keep in mind that some programs, even programs highly ranked by the OPC, might not fit the schedule due to exhaustion of a particular combination of observing conditions (Moon illumination, Seeing, etc.). Typically these cases occur when proposals request highly demanded RA’s where competition with Large Programs and higher ranked programs reaches a maximum. While the number of highly ranked programs that do not fit a particular

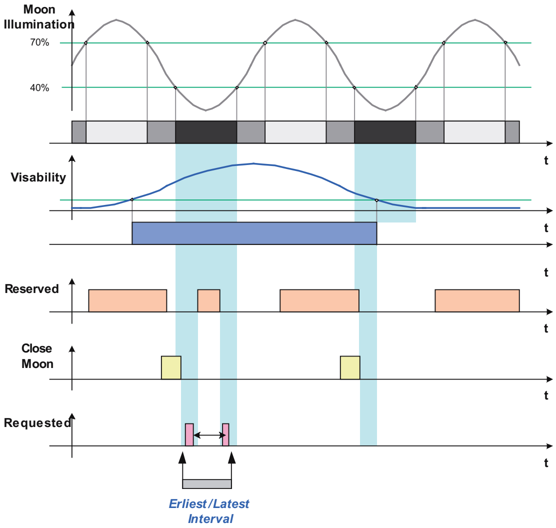


Figure 8: Illustration of the way the scheduler determines the Earliest/Latest Interval where a VM run containing two sub-runs may be scheduled. For simplicity, the figure shows only some of the constraints applied. In reality many more constraints such as critical and avoid-dates, linked runs, proper half-nights, scheduling runs of the same PI close together, minimizing of instrument setup time, etc. are applied.

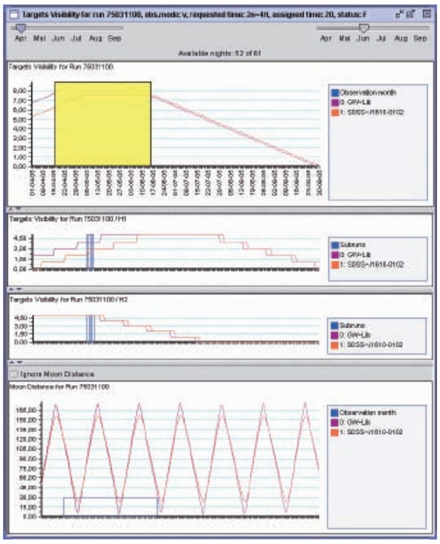


Figure 9: On the upper panel *TaToo* shows the target visibility (number of observable hours per night) for each target and the time window (the yellow box) in which the observation run may be scheduled. The second and the third panels show the visibility during the first (H1) and the second (H2) half-nights. The fourth panel illustrates the angular distance of each target to the moon. The blue rectangle drawn at 30° shows the minimal allowed angular distance.

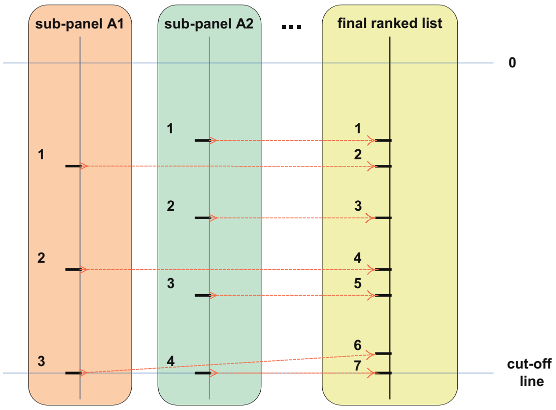


Figure 10: *TaToo* generates the final ranked list by normalizing and merging the lists of all eight OPC sub-panels: (1) For each sub-panel the list of proposals above the cut-off line is normalized between 0 and the cut-off line. (2) The normalized lists of all sub-panel are merged together. (3) In case proposals on the final ranked list overlap (like proposals A1, 3 and A2, 4 on the figure), the proposal submitted earlier is given advantage and is ranked higher. (4) Steps 1–3 are repeated for the proposals below the cut-off line.

schedule is very small (typically a few programs per semester), even these could be avoided if proposers find targets in less demanded RA's (see Alves & Lombardi 2004).

Acknowledgements

I would like to thank Dr. Vassil Lolov for the expertise, bright ideas, and motivation given to this project. Dr. Lolov worked on the TaToo project under contract with ESO. I also would like to thank the rest of the VISAS team as well as all ESO colleagues that helped with suggestions during the development of TaToo.

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ALMA News

Tom Wilson, European Southern Observatory

The Current Status of the Antenna Procurement

Presently the ALMA antenna procurement process is being delayed until further tests of the prototype antennas in Socorro NM, USA are finished. These tests involve some astronomical measurements, so winter is the most favorable time period. Once the tests are finished the results will be evaluated and a decision about the choice of ALMA antenna will be made. As all should understand, great caution is needed in reaching this decision, since the ALMA antennas will be the largest single investment in the project.

ESAC members

From Janunary 2005, José Cernicharo has become the Spanish member of the European Science Advisory Committee (ESAC). He replaces Rafael Bachiller. The names of the other national members are to be found at the web site *http://www.eso.org/projects/alma/newsletter/almanews2/ESAC*.

The Present Status of the ALMA Regional Center

The concept of the ALMA Regional Center (ARC) for Europe has been discussed by the European Science Advisory Committee (ESAC) in September 2003. This discussion is summarized in an appendix to the ESAC report. After further discussions within the European ALMA Board, the STC and ESO Council, the ESO Council approved a "Call for Expressions of Interest", with the request to submit letters of intent by 31 October 2004. Seven replies have been received. These will be discussed in a face-to-face meeting at ESO in early 2005 with the groups involved. Thus progress is being made on the organization of ARCs, and we will provide more details in future issues of *The Messenger*.

For those interested in the background, the ARC functions are divided into "User Support", which is funded within the ALMA project, and "Science Support" which is not a part of the basic ALMA funding plan. Recent accounts of the "User Support" are to be found at the web site: *http://www.eso.org/projects/alma/meetings/gar-sep04/Silva_Community_Garching.pdf*

For a description of "Science Support", see the web site *http://www.eso.org/projects/alma/meetings/gar-sep04/Wilson_Community_Garching.pdf*

For other presentations of functions given at the ALMA Community Day, see *http://www.eso.org/projects/alma/meetings/gar-sep04/*

Upcoming Events

There will be a workshop entitled "SZ Effect and ALMA" on 7–8 April 2005, at Orsay, in the Paris area. For further information and registration, email *Pierre.Cox@ias.u-psud.fr*

Planning has been started for a "Global ALMA Meeting" to be held in Madrid in 2006. This will be the first world-wide ALMA science meeting since the Washington DC meeting in 1999. The local organization of the meeting will be headed by Rafael Bachiller (OAN), while the scientific organization will be led by the Alma Scientific Advisory Committee.

View at the ALMA site on the Zona de Chajnantor. The APEX antenna is visible in front of the Cerro Chajnantor.