`degfinder` — Event rate based degeneracy finding in GLoBES

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IMPORTANT NOTICE: It is important to keep in mind that degeneracy finding is not a foolproof process. The performance of `degfinder` depends critically on the way it is configured by the user. For example, it is the user's responsibility to determine which parameters need to be scanned over in the pre-scan, which parameter correlations need to be taken into account, etc. If a mistake is made, results may be too optimistic, and it is often hard to notice when this happens. If your plots show funny features (kinks, spikes, tiny islands of good sensitivity), this is often an indication that degeneracy finding has gone wrong. Once again, **`degfinder` MUST NOT BE USED AS A BLACK BOX!**

1 Introduction

In a fit to data from a high-precision neutrinon oscillation experiment, one often has to deal with the problem of multiple degenerate solutions in the high-dimensional space of oscillation parameters. For example, the two cases $\Delta m^2_{31} > 0$ (normal mass hierarchy) and $\Delta m^2_{31} < 0$ (inverted mass hierarchy) often cannot be distinguished ("mass hierarchy degeneracy"). The fitting algorithm in GLoBES is based on *local* minimization of χ^2 in the space of oscillation parameters and systematic nuisance parameters. This local minimization can only find one degenerate solution at a time. For example, if a $\Delta m^2_{31} > 0$ is used as a starting value (the `in` parameters passed to `glbChiNP` etc.), the minimizer will usually converge into a normal hierarchy solution and ignore the inverted hierarchy solution. This may lead to results that are too optimistic, and hence it is mandatory to address the problem of degenerate solutions carefully.

This is the aim of the `degfinder` add-pon. The function `degfinder` first performs a rough scan (the so-called *pre-scan*) of part of the parameter space during which many features like systematic uncertainties and parameter correlations are switched off to improve speed. Which part of the parameter space is scanned over is determined by the user. The pre-scan provides rough estimates for the locations of the local χ^2 minima, and each of these is then used as a starting points for a full-fledged minimization including all features.

2 Installation

To use degfinder in your GLoBES application, simply `#include` the header file `degfinder.h` in your source code and add the source file `degfinder.c` to your `Makefile` so that it is compiled and linked to your executable.

Note that `degfinder` is written in the GNU version of C99. To compile it with `gcc`, use the option `-std=gnu99`. I haven't tested `degfinder` with other compilers, so I cannot exclude that some tweaking may be necessary to compile it with them.

3 Usage

The syntax of `degfinder` is

```
int degfinder(const glb_params base_values,
  const int n_prescan_params, const int *prescan_params,
  const double *prescan_min, const double *prescan_max,
  const int *prescan_steps, const glb_projection prescan_proj,
  const glb_projection fit_proj, int *n_deg, glb_params *deg_pos,
  double *deg_chi2, const long flags);
```

The arguments are

`base_values`	Vector of oscillation parameters. Parameters that are not scanned in the pre-scan (i.e. parameters that are not included in `prescan_params`) are treated in the same way as `in` parameters passed to `glbChiNP` and similar function. This means that if a parameter is declared as `GLB_FIXED` in `prescan_proj` or `fit_proj`, it is assumed to be known with a zero uncertainty in the pre-scan or during the final fit, respectively. The value of a parameter that is declared as `GLB_FREE` in `prescan_proj` or `fit_proj` is used as starting values for local minimizations of χ^2 with respect to that parameter during the pre-scan or during the final minimization, respectively. The `base_values` of parameters included in `prescan_params` are ignored.
`n_prescan_params`	The number of parameters that should be scanned over during the pre-scan.
`prescan_params`	A list of parameters to be scanned over during the prescan. Parameters are referred to by their numerical index, e.g. `GLB_THETA_12`, `GLB_THETA_13`, etc. There should be `n_prescan_params` entries in `prescan_params`.

`prescan_min`, `prescan_max`, `prescan_steps`	Parameter ranges for the pre-scan. For each entry of `prescan_params`, a minimum value, a maximum value, and a number of steps is given. The number of points sampled for each parameter is the number of steps plus one. Note that all parameters except θ_{13} are scanned on a linear scale, while θ_{13} is scanned on a logarithmic scale in $\sin^2 2\theta_{13}$. For example, if `prescan_min = -3`, `prescan_max = -1`, $\sin^2 2\theta_{13}$ will be varied between 10^{-3} and 10^{-1}, using `prescan_steps+1` logarithmically spaced sampling points.
`prescan_proj`	The projection to be used in the pre-scan. Typically, most or all entries will be declared as `GLB_FIXED` to make the pre-scan as efficient as possible. Sometimes, however, it may be necessary to declare one or several parameters as `GLB_FREE` to tell `degfinder` to do a local minimization over that parameter even during the pre-scan.
`fit_proj`	The projection to be used in the final fit. Typically, most parameters will be declared as `GLB_FREE` here.
`n_deg`	Input: Pointer to an integer giving the maximum number of degenerate solutions to accept (the length of the vectors `deg_pos` and `deg_chi`). Output: The number of degenerate solutions actually found.
`deg_pos`	An array of pointers to `glb_params` structures that will be filled with the locations of the degenerate solutions in the space of oscillation parameters.
`deg_chi`	This array will be filled with the χ^2 values of the degenerate solutions.
`flags`	Some flags that control the behavior of `degfinder`. `DEG_NO_NH` Omit normal hierarchy solutions. `DEG_NO_IH` Omit inverted hierarchy solutions. `DEG_NO_SYS` Switch off systematics even during the final fit (systematics are always off during the pre-scan). `DEG_NO_CORR` Switch off parameter correlations. Equivalent to declaring all parameters as `GLB_FIXED` in both `prescan_proj` and `fit_proj`. `DEG_NO_DEG` Switch off degeneracies. Equivalent to setting `n_prescan_params = 0`. Note that in this case, `degfinder` should behave just like `glbChiNP`.

4 `degfinder` and non-standard interactions

`degfinder` works together with my non-standard interaction code. If you want to use this feature, include `nsi.h` in the header of `degfinder.c`. If non-standard parameters are included in the pre-scan, `degfinder` will step through the non-standard phases on a linear scale, while the absolute values of the non-standard parameters are scanned on a log scale. Consequently, for the absolute values of the non-standard paremeters, `prescan_min` and `prescan_max` should be logarithmic. For example, a range $[-3, -1]$ means that this parameter will be varied between 10^{-3} and 10^{-1}, with logarithmically spaced sampling points. Note that degeneracy finding in high dimensional NSI parameter spaces can be extremely inefficient.