UNIVERSITÀ DEGLI STUDI
DI TRENTO

AEI, Hannover
Leibniz Universität Hannover

What is LTPDA?

M Hewitson for the LTP Team
GSFC
11th October 2011

Outline

- Why LTPDA?
- Formalities
- Installation
- Possible threads:
  - Boot Camp
    - Topic 1: Introducing LTPDA - the basics
    - Topic 2: Preprocessing data
    - Topic 3: Spectral analysis
    - Topic 4: Transfer functions and digital filters
    - Topic 5: Fitting data
  - Advanced Topics
    - extension modules
    - writing your own methods, models

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esa

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Not a commercial product!

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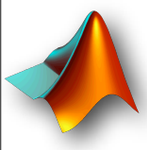

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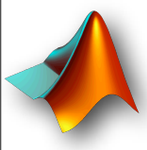


Not a commercial product!

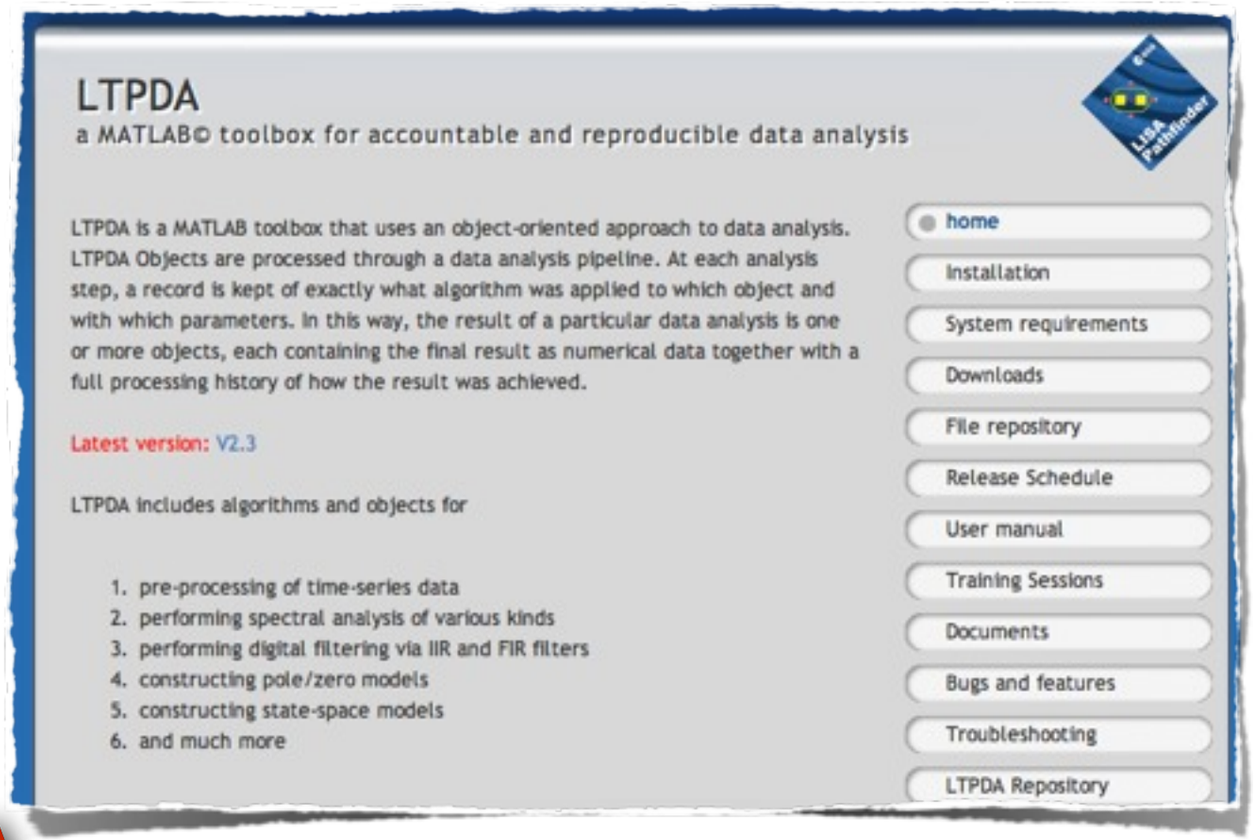
- We have about 3 FTEs currently working on the toolbox
- Total effort so far is about 15 man-years
- Feedback is essential
- We will help whenever we can

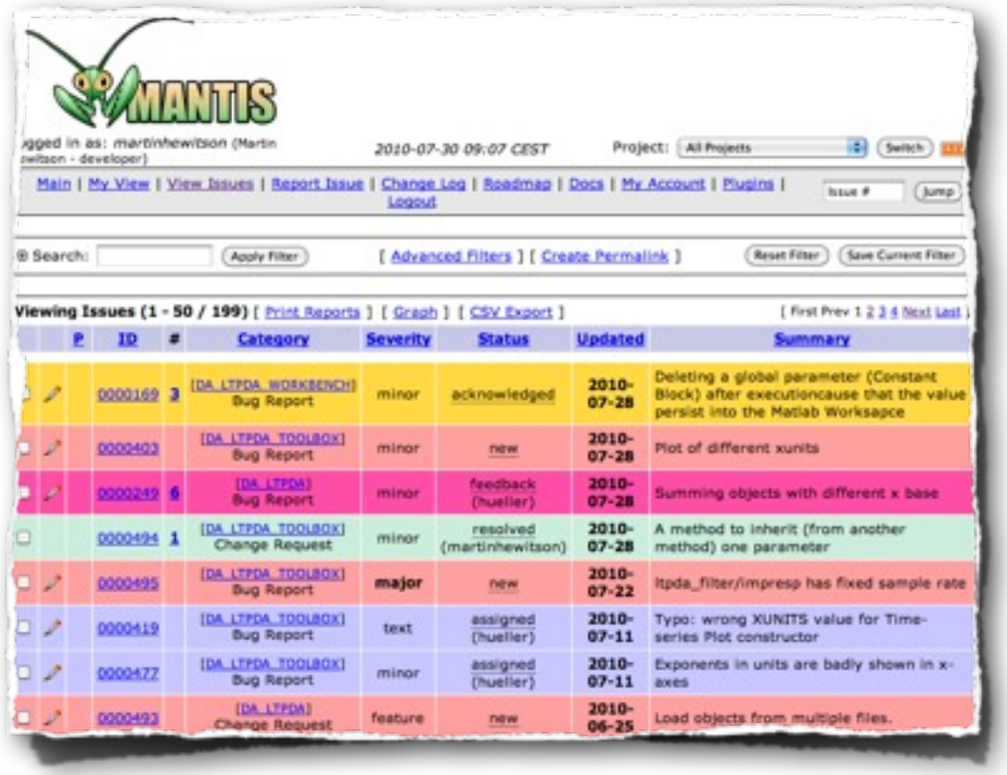
Why?

- Data analysis for LISA Pathfinder mission will be done on-line
  - allow re-planning of upcoming experiments and investigations
- Front-line analysis done in STOC
  - pre-planned data analysis pipelines for each experiment of the mission
- Off-line analysis
  - follow-up, problem solving, etc
- Results must have a long shelf-life (up to LISA commissioning)
- Requirements:
  - flexible and robust data analysis environment
  - graphical user interface (for non-programming-experts)
  - high-level of testing
  - automated capture of processing chain
    - data doesn't exist in isolation

Formalities

- LTPDA:
  - http://www.lisa.aei-hannover.de/ltpda/
- Bugs and features:
  - https://ed.fbk.eu/ltpda/mantis/





Mailing lists

- ltpda_releases@aei.mpg.de
- http://lists.aei.mpg.de/cgi-bin/mailman/listinfo/ltpda_releases
  - for releases of LTPDA

- ltpda_users@aei.mpg.de
- http://lists.aei.mpg.de/cgi-bin/mailman/listinfo/ltpda_users
  - for LTPDA users

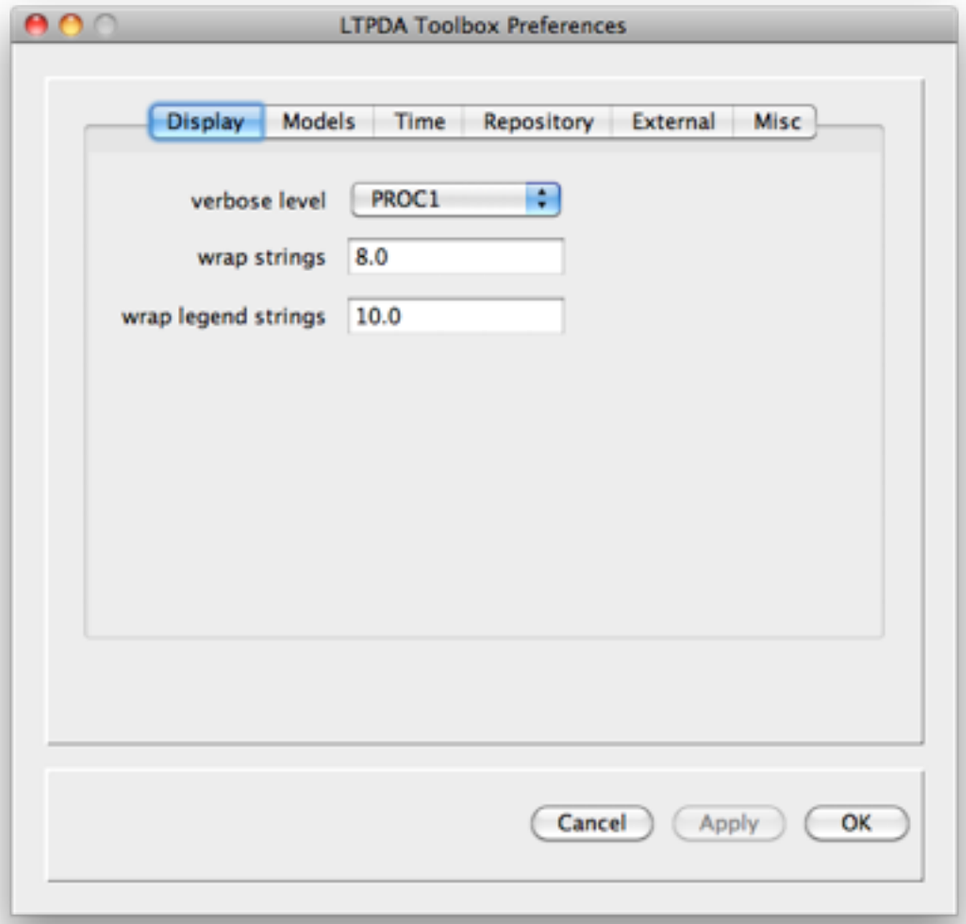
- ltpda_dev@aei.mpg.de
- http://lists.aei.mpg.de/cgi-bin/mailman/listinfo/ltpda_dev
  - for core development team

- ltpda_cvs@aei.mpg.de
- http://lists.aei.mpg.de/cgi-bin/mailman/listinfo/ltpda_cvs
  - for LTPDA CVS commit mails

- ltp_da_meeting@aei.mpg.de
- http://lists.aei.mpg.de/cgi-bin/mailman/listinfo/ltp_da_meeting
  - for meeting announcements

Installation

1. Download 2.5.beta version from
   1.1. http://www.lisa.aei-hannover.de/ltpda/
2. Unzip to somewhere
3. Start MATLAB
4. File->Set Path...
5. Click ‘Add with Subfolders...’
6. Navigate to the ltpda_toolbox folder you unzipped
7. On MATLAB terminal
   7.1. >> ltpda_startup
      7.1.1. (you can add this command to you normal startup.m file)
8. Set preferences
   8.1. for now just click ‘Apply’ and close the GUI



Post-installation steps

- Test installation
  - >> run_tests

- Install graphviz
  - see LTPDA user manual (>> doc)
    - LTPDA Toolbox
      - Getting Started with the LTPDA Toolbox
        - Additional 3rd-party software

http://www.lisa.aei-hannover.de/ltpda/usermanual/ug/additional_progs.html

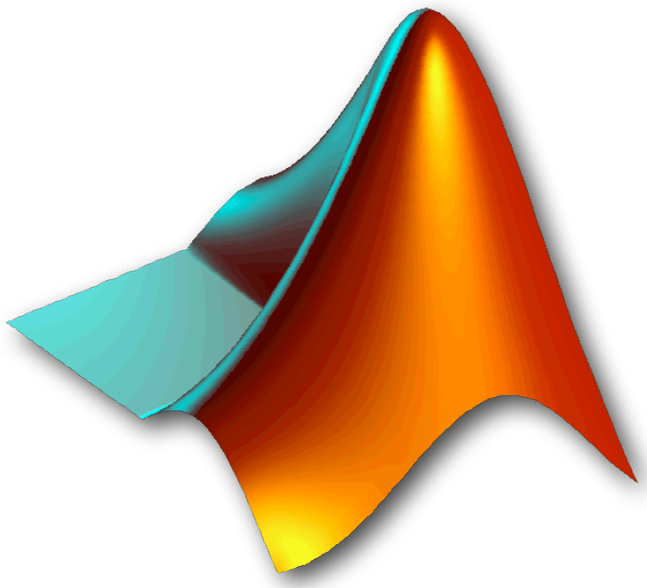
Updating the toolbox

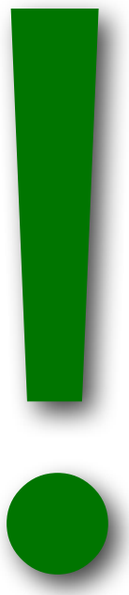
- Remove old toolbox from MATLAB path
  - File -> Set Path
  - Select all in list containing '`ltpda_toolbox`'
  - Click 'Remove'
- Install new toolbox as per previous instructions

Submitting a bug or feature request

- Go to https://ed.fbk.eu/ltpda/mantis/
- Self-sign-up
  - click ‘Signup for a new account’
- Once your account is active, you can log in

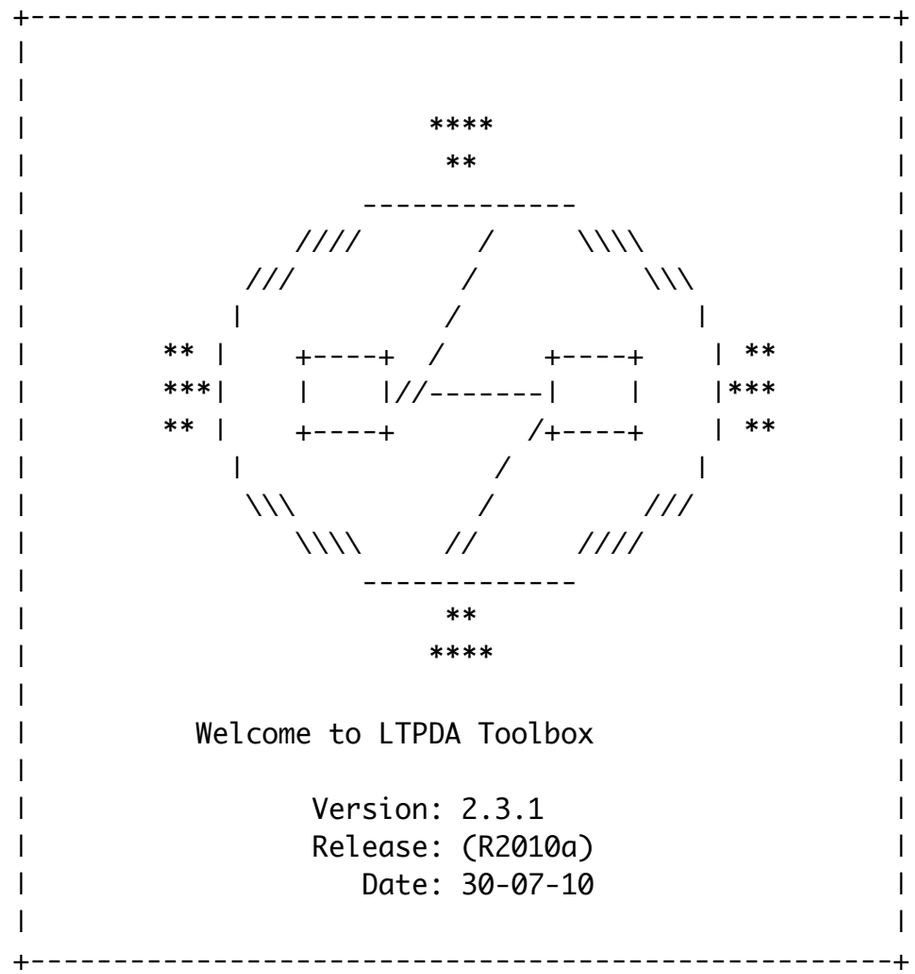
- To report an issue:
  - First search the existing issues in case your problem is covered!
  - Click ‘Report Issue’
  - Choose project ‘DA_LTPDA’
  - Select ‘bug report’ or ‘change request’
  - Complete the form with as much information as possible





Topic 1

- The basics
  - Object-oriented programming (for beginners)
  - Analysis Objects
  - How history tracking works
  - Other objects
  - Parameter lists
  - Building objects
  - Setting object properties
  - Viewing history
  - Making time-series AOs
  - Basic math
  - Saving and loading
  - Reading data files
  - Writing LTPDA scripts
- Hands-on

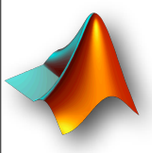


Object-oriented programming

- Learn these words:
  - class
  - object
  - instance
  - method
  - constructor
  - property
  - inheritance

Class

- A class is a description of an object
- Examples:
  - aeroplane, house, vehicle, animal
  - algorithm, colour, sentence



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Object, instance

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- Examples:
  - Airforce 1 (*aeroplane*), me (*person*), garfield (*cartoon cat*)
  - mean (*algorithm*), red (*color*), “isn’t this easy?” (*sentence*)

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method

- Something that acts on an object (instance of a class)
- Examples:
  - ‘start’ a ‘car’ - ‘start’ is a method of the class ‘car’
  - ‘start’ my car - use the method ‘fly’ on my car
  - mean(x) - use the method ‘mean’ on the data object ‘x’

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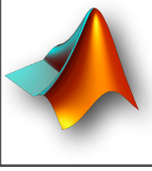
construct

- A special method of a class which builds an instance of the class (builds an object)
  - normally the method has the same name as the class

- Examples:
  - car('blue') - builds a blue car
  - animal('dog', 'brown') - builds a brown dog which is a type of animal



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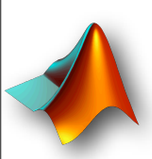
- A property is one aspect of a class (or object)
- Examples:
  - a ‘car’ might have properties:
    - make, color, top-speed, cost
  - an algorithm might have properties
    - input-type, different configuration parameters



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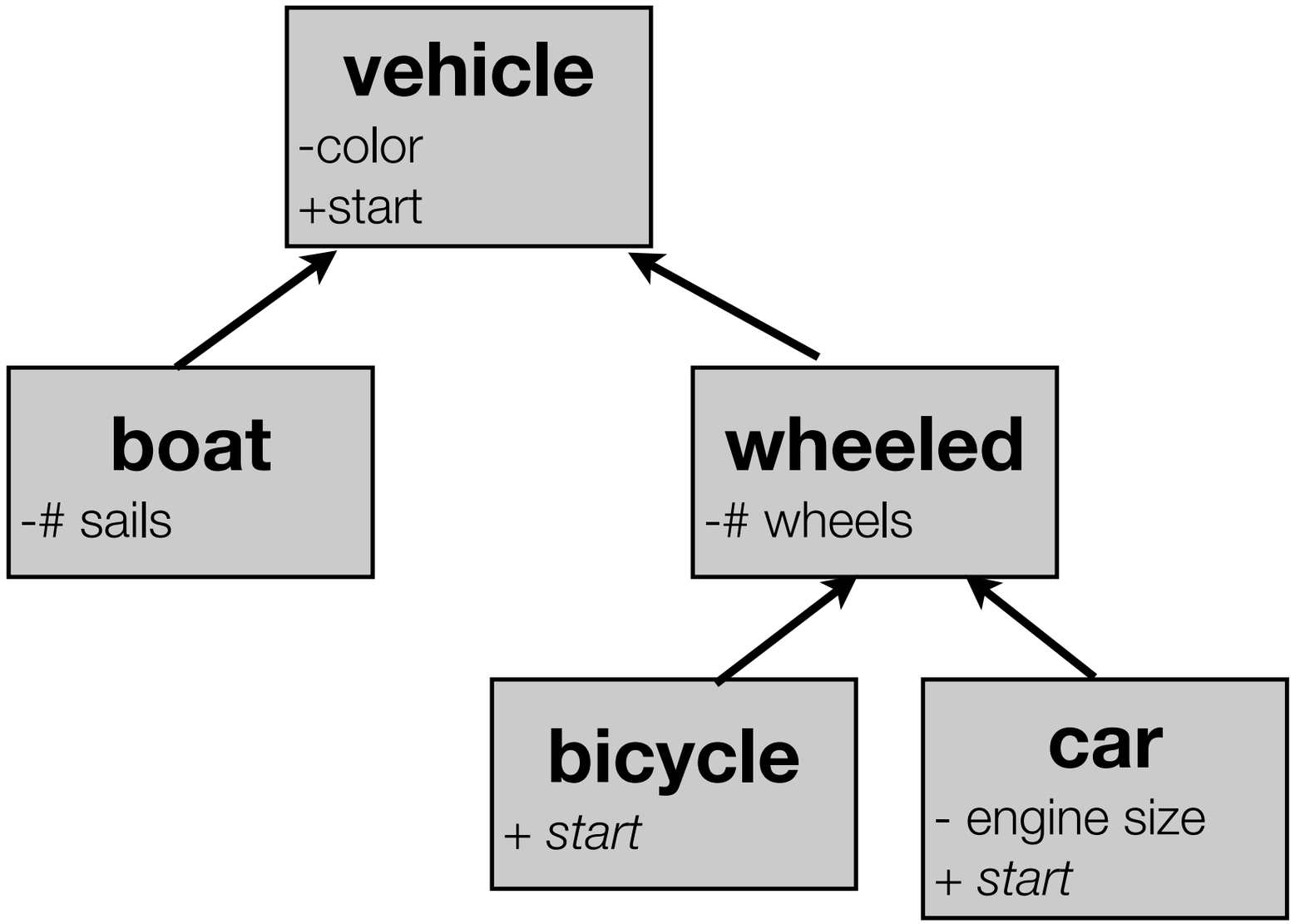
inheritance

- classes can inherit behaviour (methods and properties) from other classes



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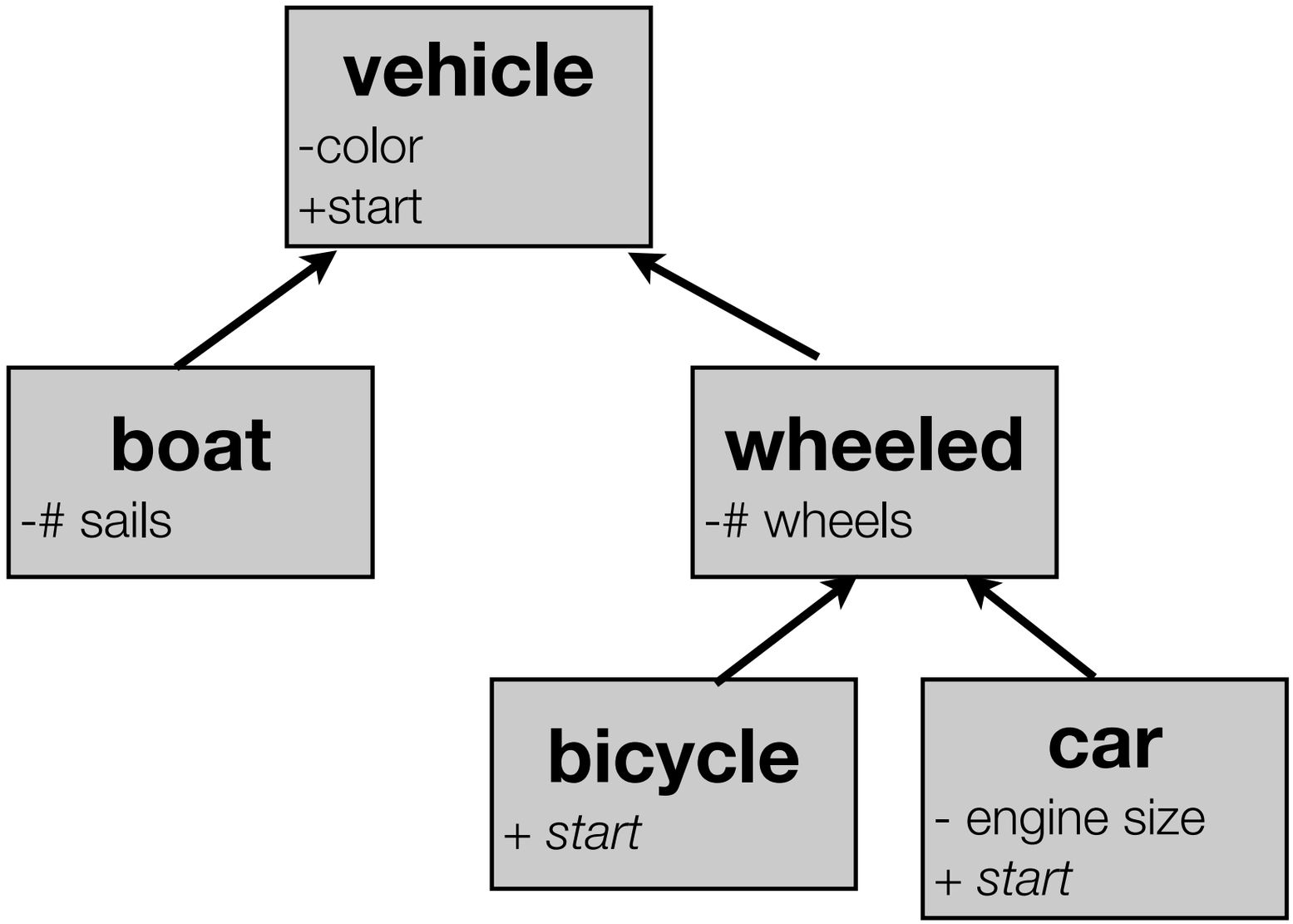
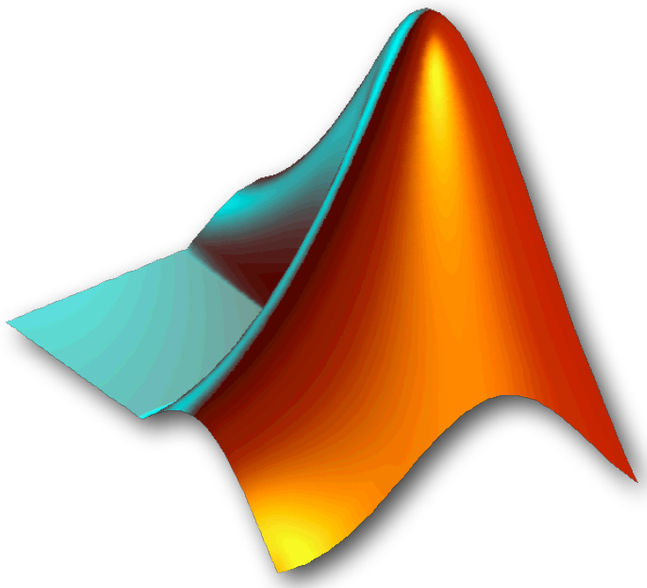
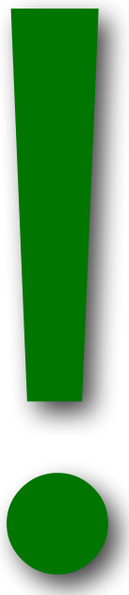
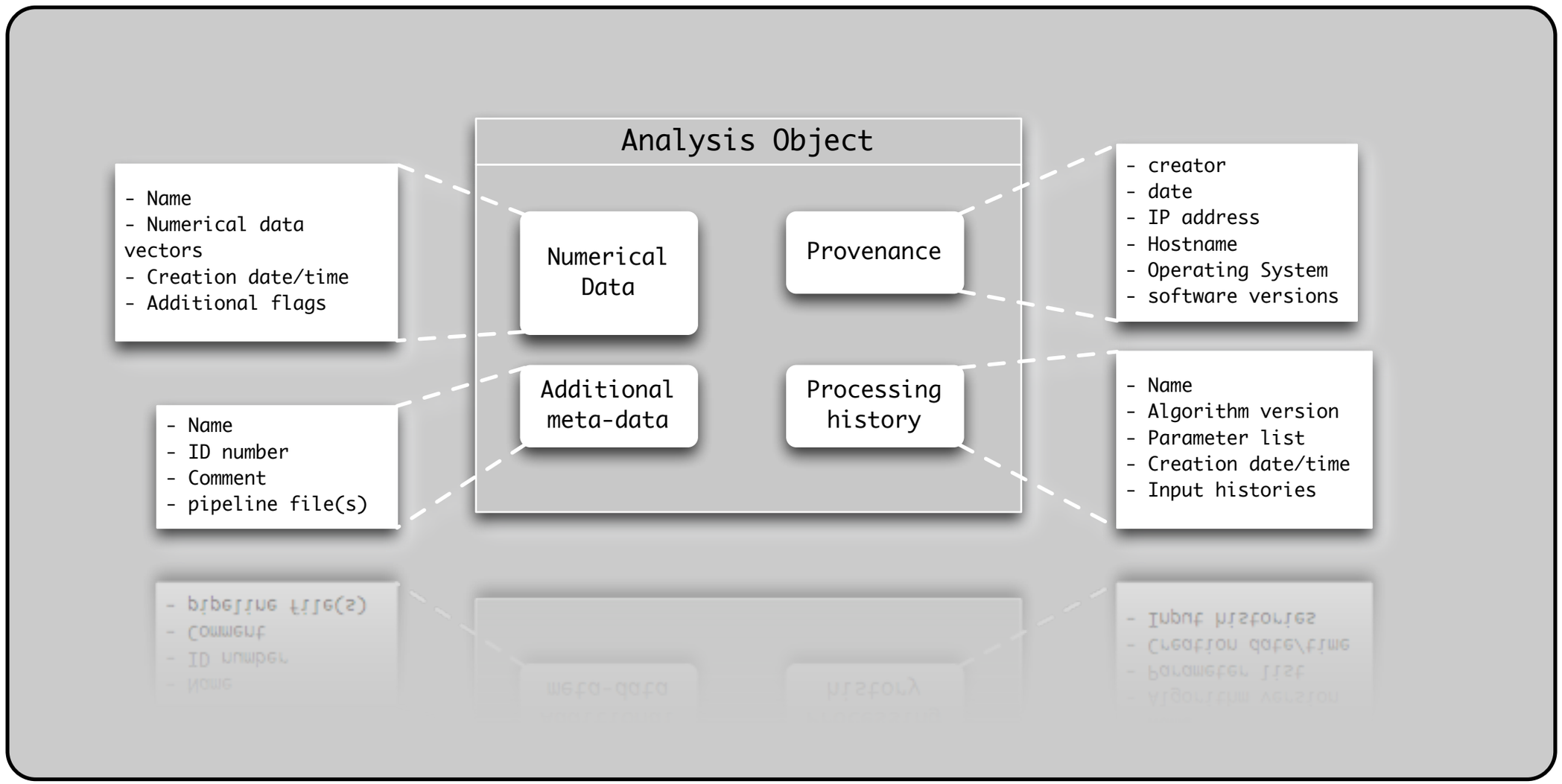






Analysis Objects

- Aim to store data products



AO Methods

```
>> methods ao

Contents              detrend               hist_gauss            mdc1_ifo2acc_inloop   rotate                std
abs                   dft                   hypot                 mdc1_ifo2cont_utn     round                 straightLineFit
acos                  diag                  ifft                  mdc1_ifo2control      sDomainFit            string
angle                 diff                  imag                  mdc1_x2acc            save                  submit
ao                    display               index                 mean                  scale                 sum
asin                  dopplercorr           integrate             median                scatterData           sumjoin
atan                  downsample            interp                min                   search                svd
atan2                 dropduplicates        interpmissing         minus                 select                svd_fit
bilinfit              dsmean                inv                   mode                  setDescription        t0
bin_data              dx                    iplot                 mpower                setDx                 table
bsubmit               dy                    iplotyy               mrdivide              setDy                 tan
buildWhitener1D       eig                   isprop                mtimes                setFs                 tdfit
cat                   eq                    isvalid               ne                    setMdlfile            tfe
char                  eqmotion              join                  noisegen1D            setName               timeaverage
cohere                evaluateModel         lcohere               noisegen2D            setPlotinfo           timedomainfit
complex               exp                   lcpsd                 norm                  setProcinfo           times
compute               export                le                    normdist              setT0                 timeshift
confint               fft                   len                   nsecs                 setUUID               transpose
conj                  fftfilt               linSubtract           offset                setX                  type
consolidate           filtSubtract          lincom                optSubtraction        setXY                 uminus
conv                  filter                linedetect            phase                 setXunits             unwrap
convert               filtfilt              linfit                plot                  setY                  update
copy                  find                  lisovfit              plus                  setYunits             upsample
corr                  firwhiten             ln                    polyfit               setZ                  validate
cos                   fixfs                 log                   polynomfit            sign                  var
cov                   fngen                 log10                 power                 simplifyYunits        viewHistory
cpsd                  fromProcinfo          lpsd                  psd                   sin                   whiten1D
crbound               fs                    lscov                 psdconf               sineParams            whiten2D
created               gapfilling            lt                    pwelch                smallvector_lincom    x
creator               gapfillingoptim       ltfe                  quasiSweptSine        smallvectorfit        xcorr
csvexport             ge                    ltp_ifo2acc           rdivide               smoother              xfit
ctranspose            get                   max                   real                  sort                  xunits
curvefit              getdof                mcmc                  rebuild               spectrogram           y
delay                 gnuplot               md5                   removeVal             spikecleaning         yunits
delayEstimate         gt                    mdc1_cont2act_utn     report                split                 zDomainFit
demux                 heterodyne            mdc1_ifo2acc_fd       resample              spsd                  zeropad
det                   hist                  mdc1_ifo2acc_fd_utn   rms                   sqrt
```

Tracking history...

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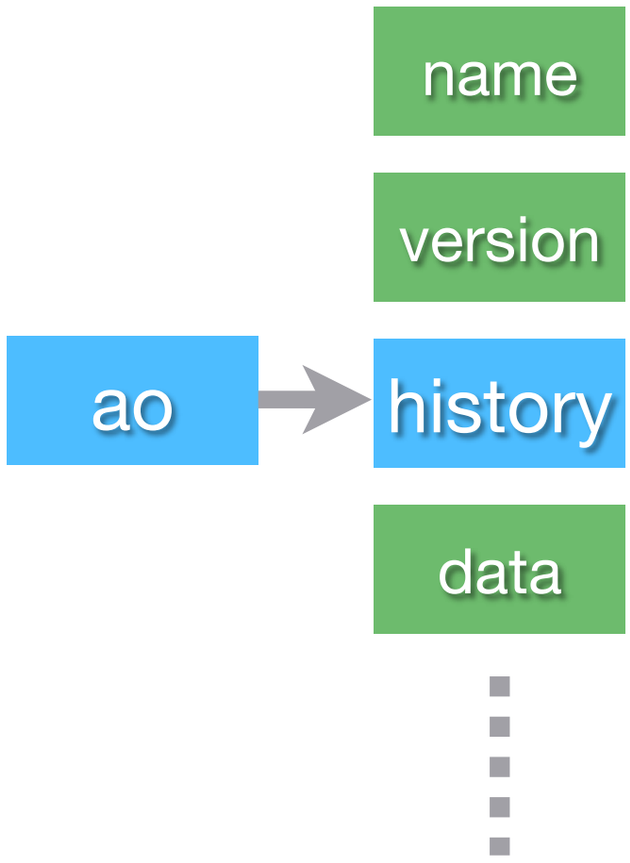

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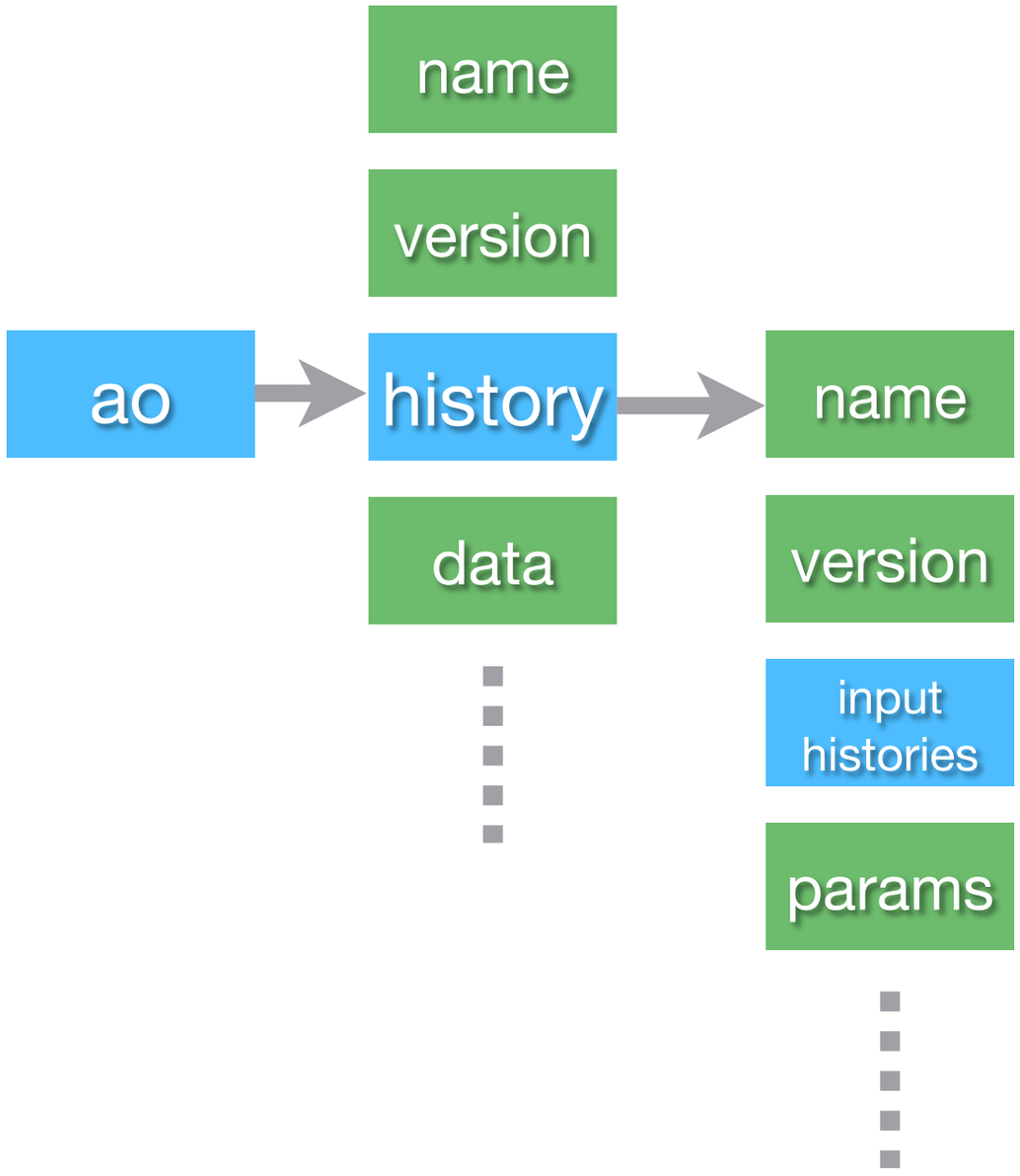

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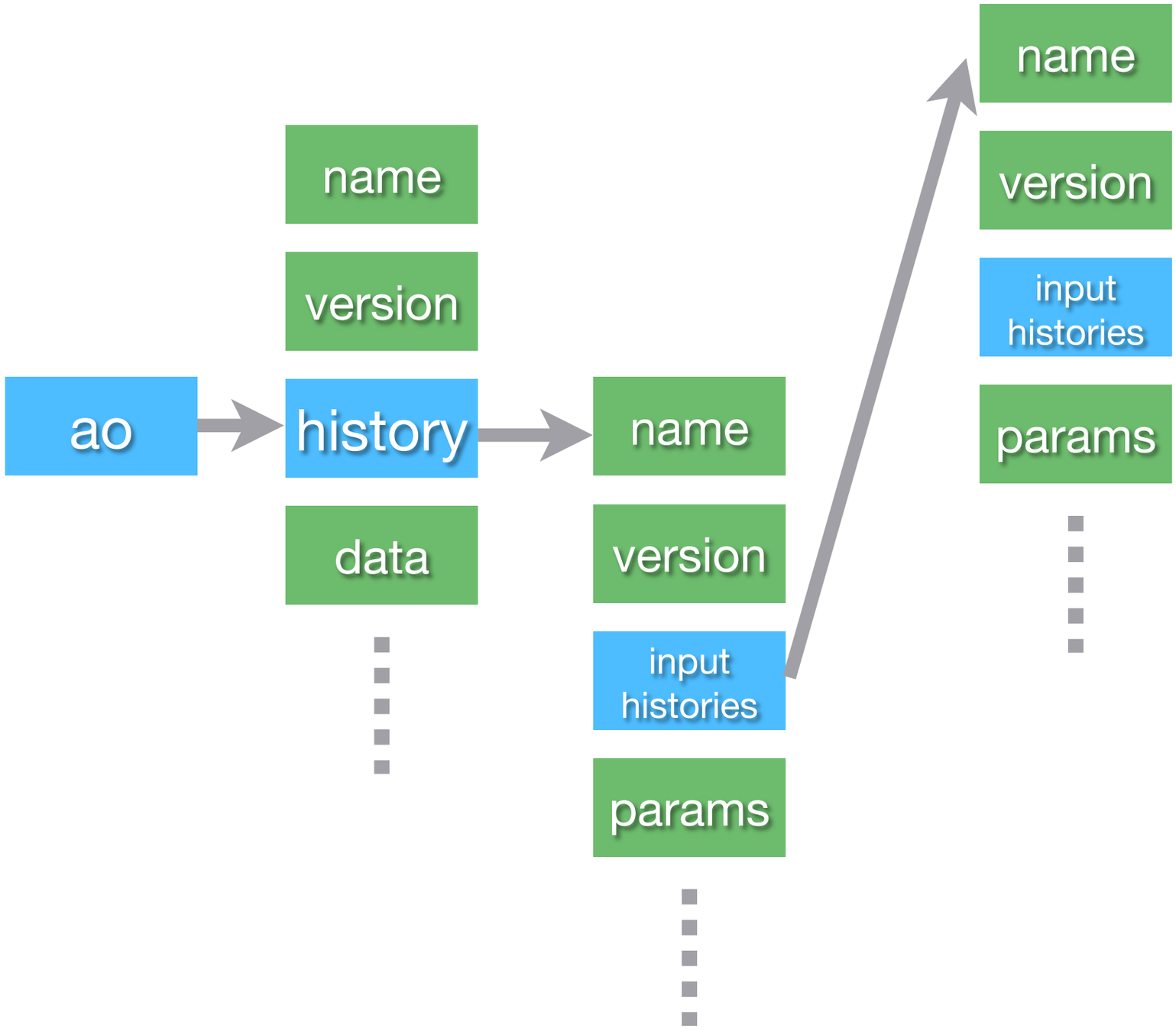

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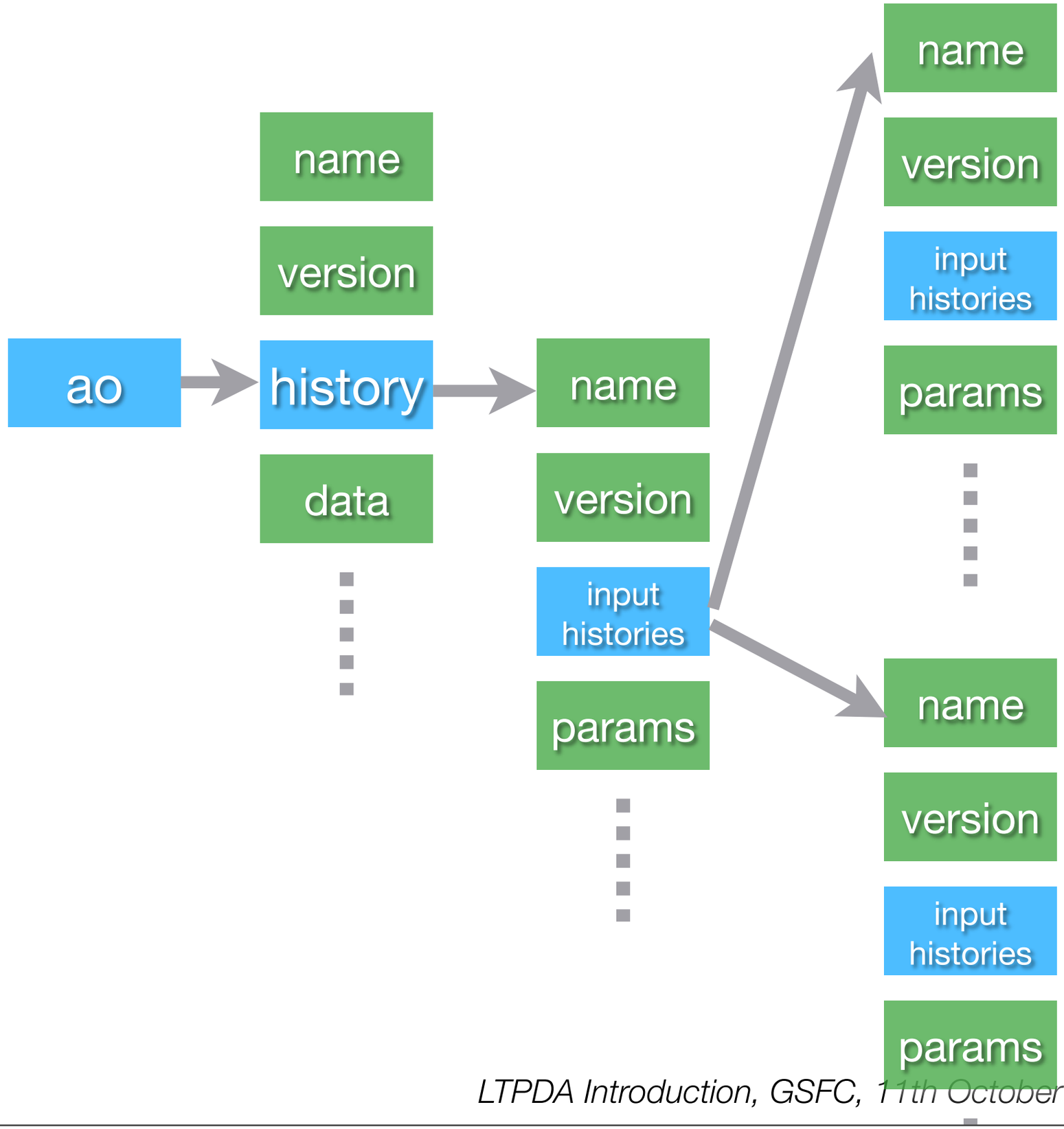

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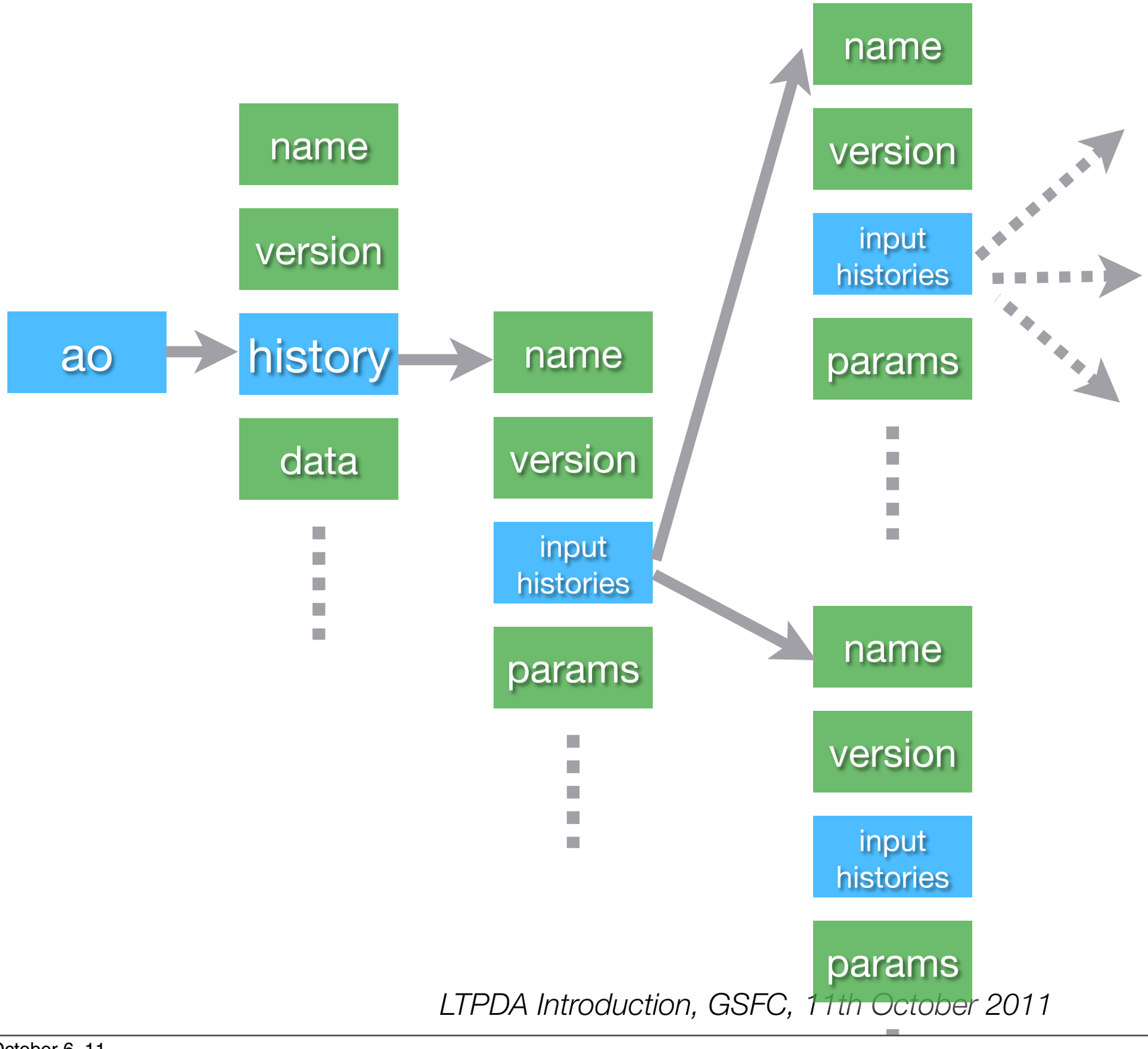
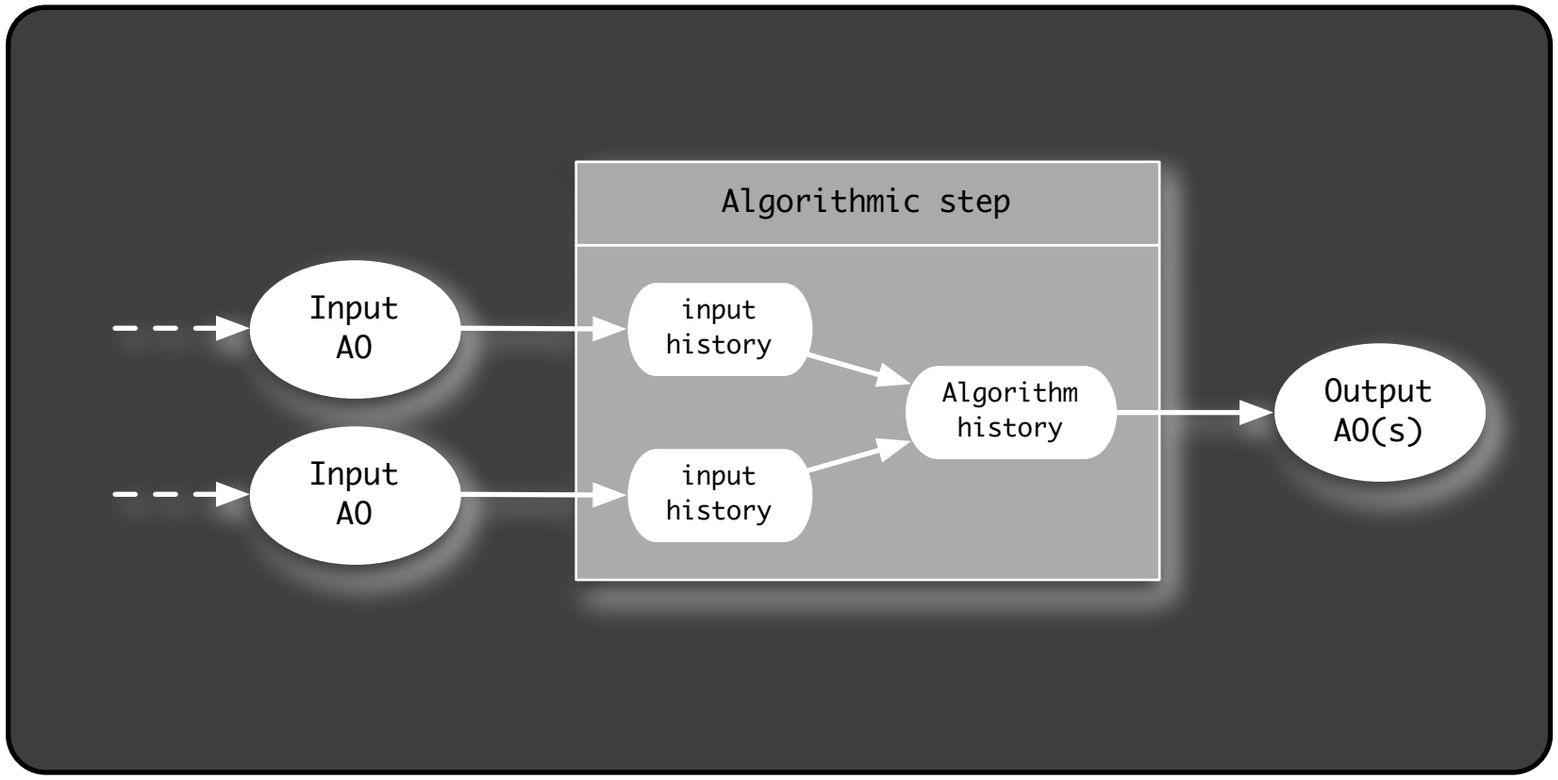
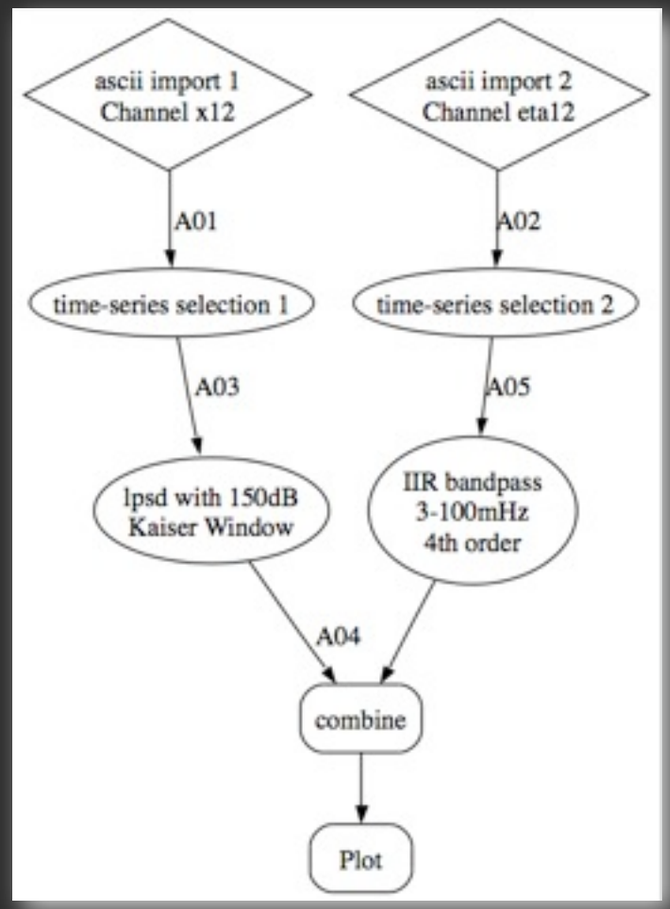


Smart algorithms

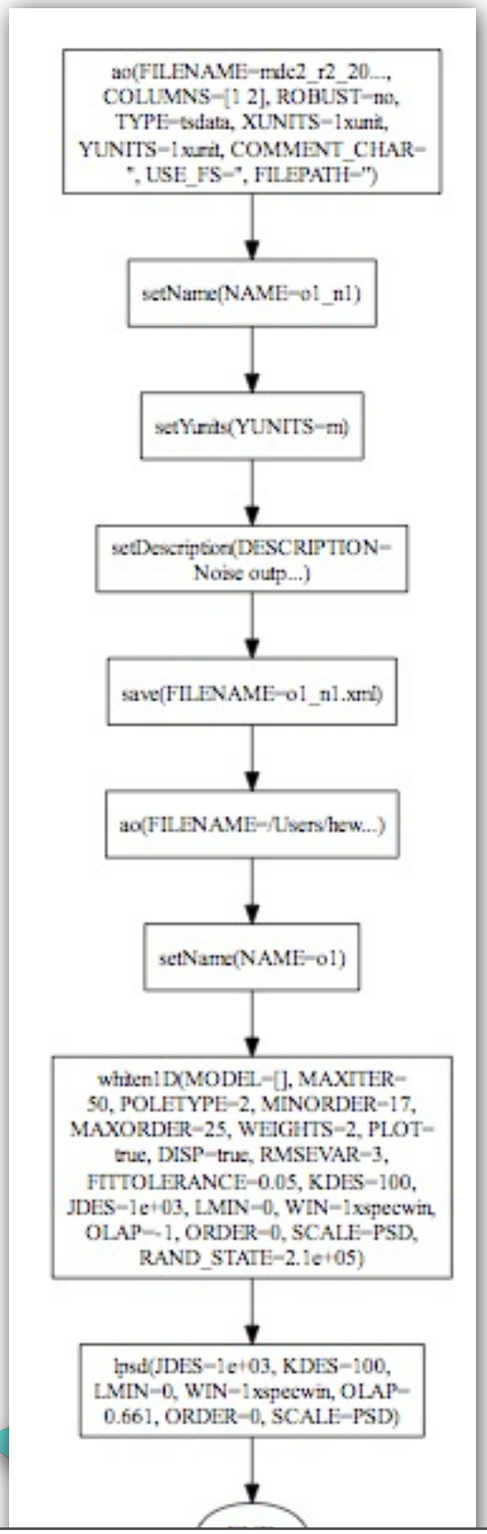
Intelligent algorithms

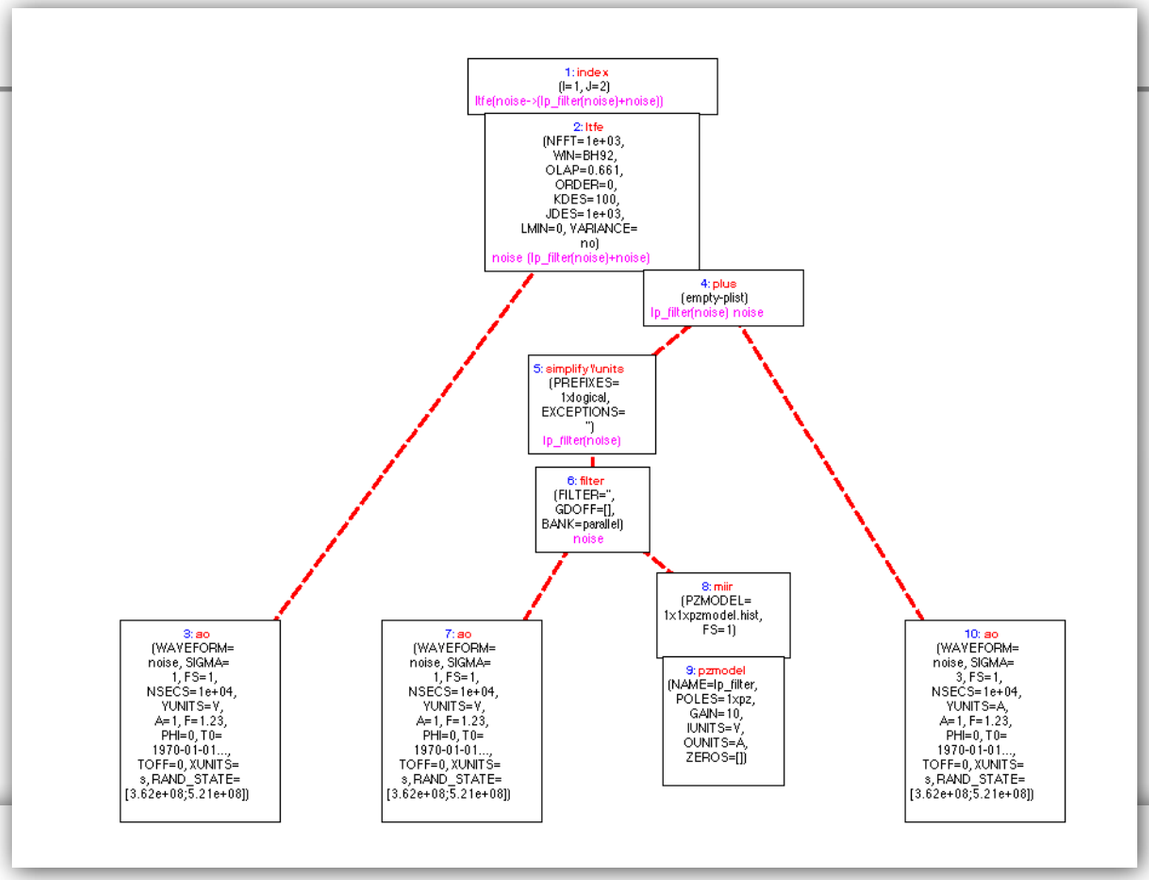


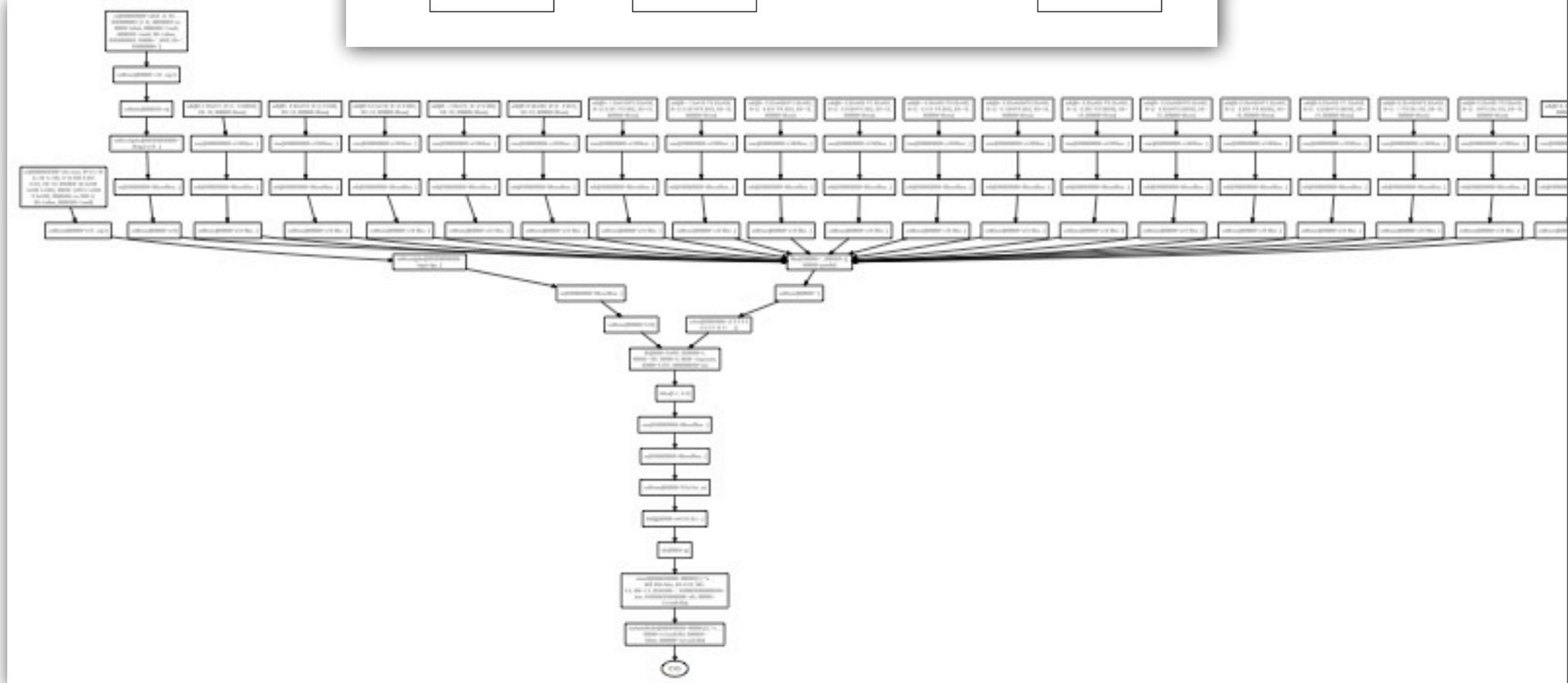


traceable results

Viewing history



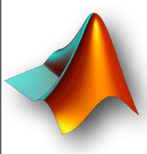




Reliving history

```
obj.type(<file>)
```
output commands needed to rebuild this object

```
robj = obj.rebuild
```
rebuild this object



Objects, Objects, Everywhere...

- The LTPDA Toolbox is fully object-oriented
- The user deals with:
  - ‘LTPDA user objects’
  - MATLAB primitives (strings, doubles, logicals, etc)
- We have 13 LTPDA User Classes
  - 'ao', 'collection', 'filterbank', 'matrix', 'mfir', 'miir', 'parfrac', 'pest', 'pzmodel', 'rational', 'smodel', 'ssm', 'timespan'
- Two ‘helper’ classes
  - ‘plist’, ‘time’

Class-diagram

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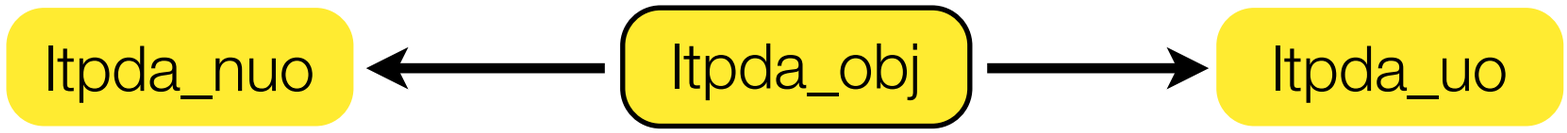

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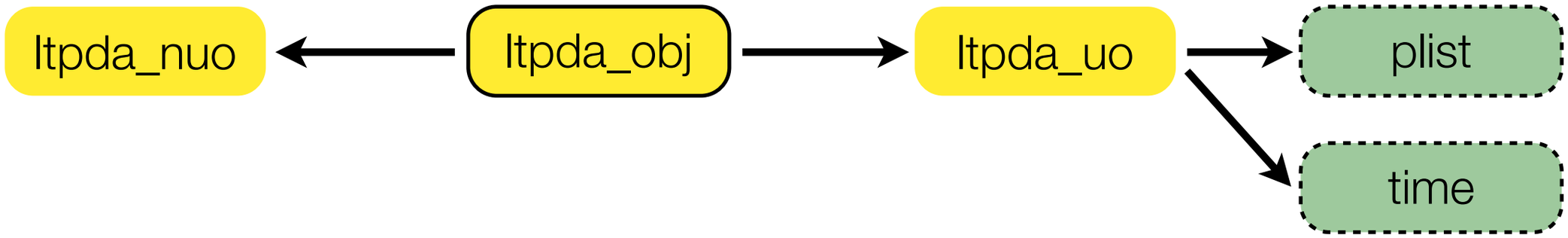

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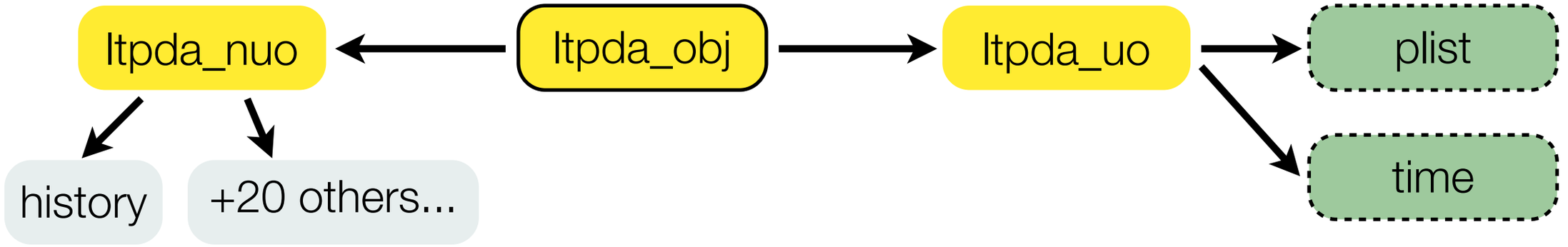

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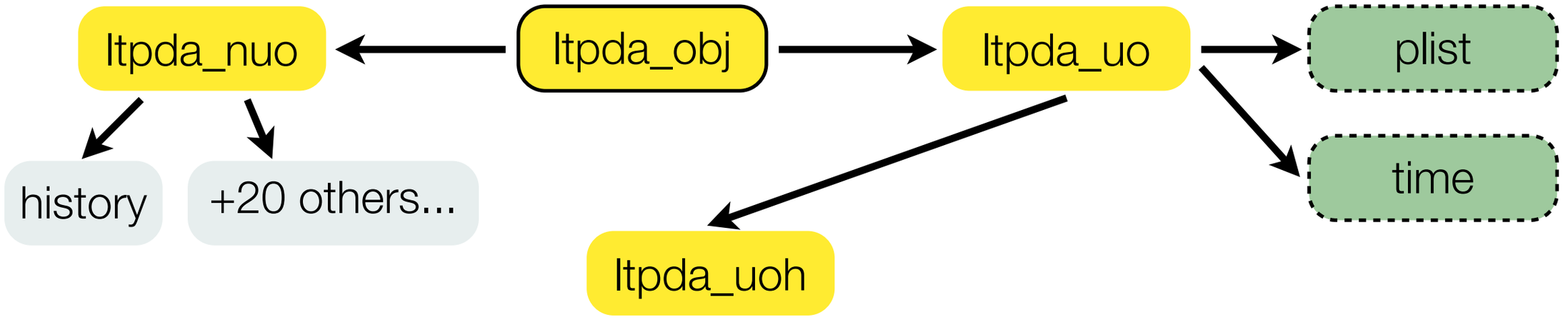

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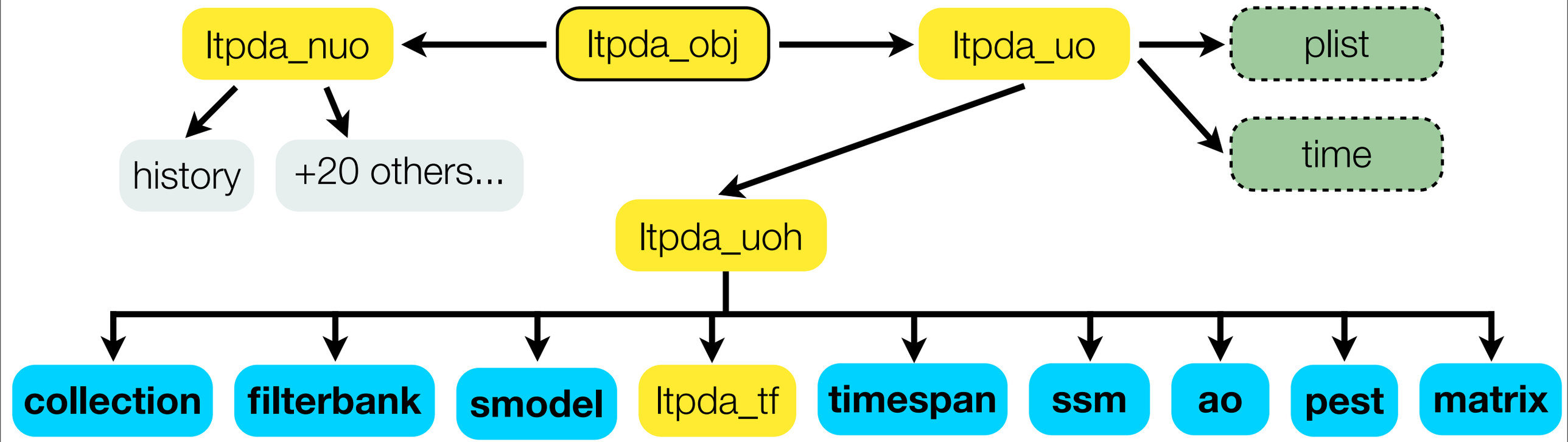

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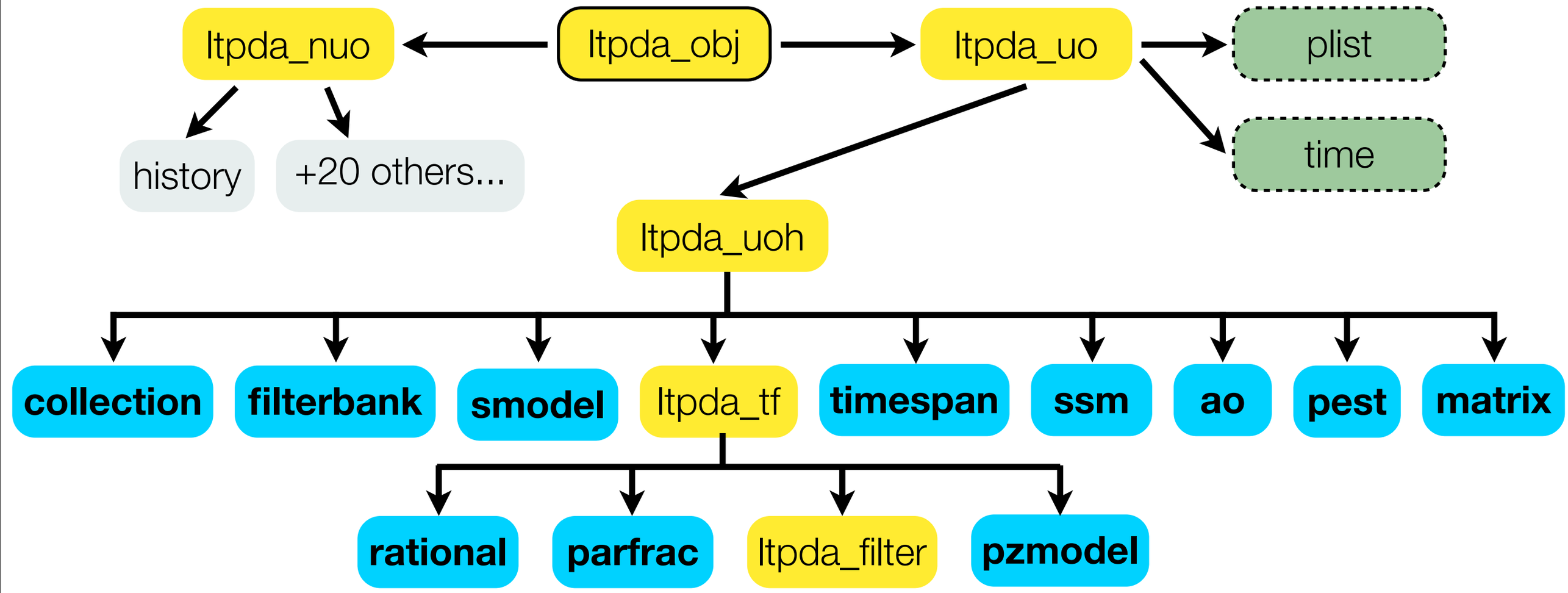

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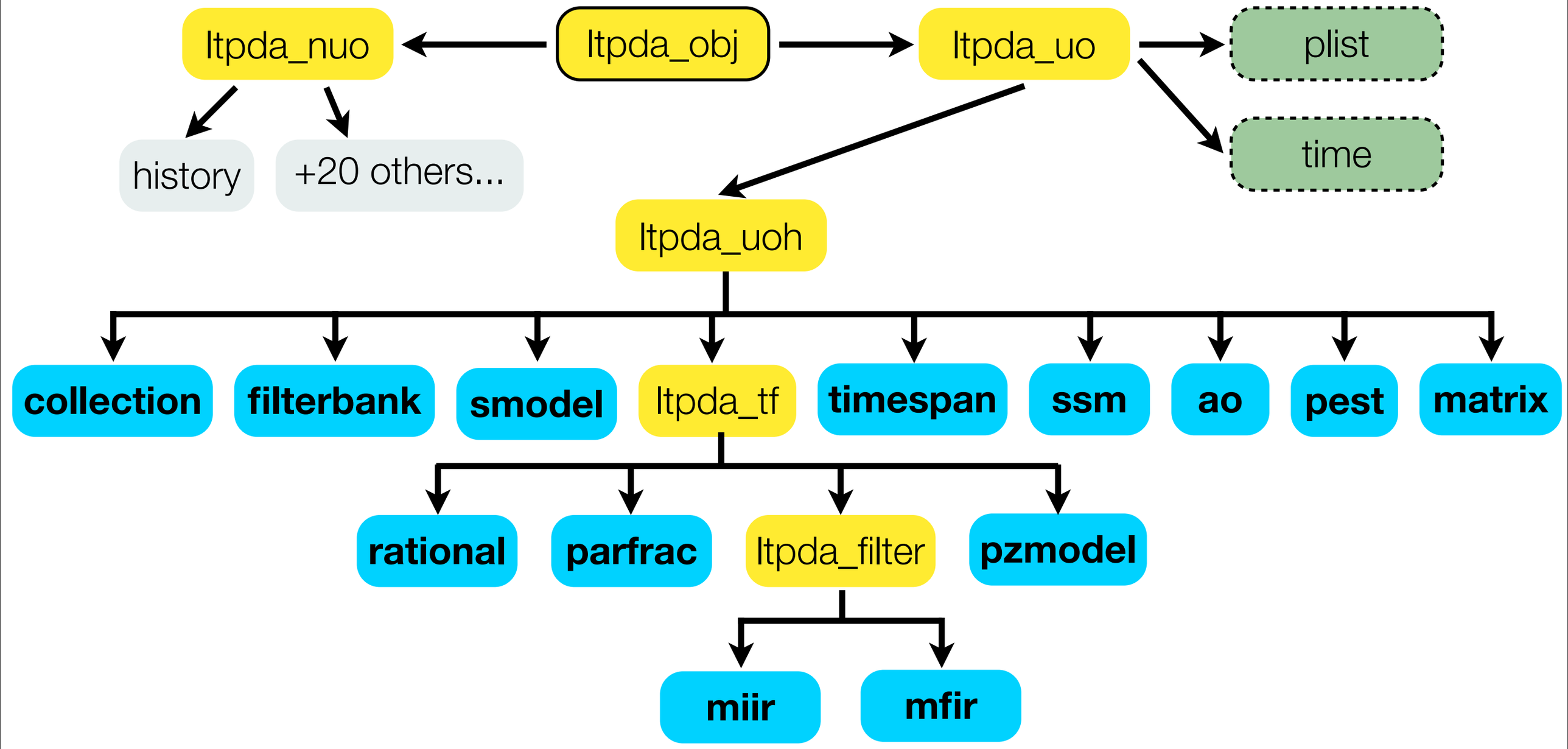


Parameter lists

- Essentially all methods and constructors are *configured* by parameter lists (`plists`)
- A parameter list has:
  - a list of parameters
  - a name (inherited)
  - a description (inherited)
  - a UUID* (inherited)
- Each parameter has a ‘key’ and a ‘value’
  - key == string
  - value == MATLAB primitive or LTPDA object

*http://en.wikipedia.org/wiki/UUID

Examples:

```
>> pl = plist
----------- plist 01 -----------
n params: 0
description:
UUID:        9d9ef3a6-52f1-4fbf-a442-f83d9d7b6b88
--------------------------------
```

Empty Parameter List

```
>> pl = plist('a', 1, 'b', 'two')
----------- plist 01 -----------
n params: 2
---- param 1 ----
key:  A
val:  1
-----------------
---- param 2 ----
key:  B
val:  'two'
-----------------
description:
UUID:        d4b59063-292c-4254-b562-0fef3fb11c17
--------------------------------
```

Parameter list with two parameters, ‘a’ and ‘b’

Building objects

- Objects are built using class constructors:
  - object = <class_name>(<arguments>)

- Examples:

```
>> a = ao
```
empty analysis object

```
>> a = ao(1)
```
analysis object with a single data value

```
>> a = ao(plist('vals', 1))
```
as above, using a plist

```
>> s = smodel('a*x+b')
```
symbolic model of a straight-line

```
>> s = mfir('filter.xml')
```
build an FIR filter by loading it from a file

```
>> pl = plist('filename', 'filter.xml')
>> s = mfir(pl)
```
as above, using a plist

Getting help

- How do I know which parameters to put in my plist?

```
>> help mfir
```

```
 MFIR FIR filter object class constructor.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

 DESCRIPTION: MFIR FIR filter object class constructor.
              Create a mfir object.

 CONSTRUCTORS:

       f = mfir()         - creates an empty mfir object.

   :
   :

 Parameter Sets

 VERSION:     $Id: mfir.m,v 1.103 2010/05/05 09:30:07 ingo Exp $

 SEE ALSO:    miir, ltpda_filter, ltpda_uoh, ltpda_uo, ltpda_obj, plist

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

Getting help

- How do I know which parameters to put in my plist?

```
>> help mfir
```

```
MFIR FIR filter object class constructor.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

DESCRIPTION: MFIR FIR filter object class constructor.
             Create a mfir object.

CONSTRUCTORS:

      f = mfir()         - creates an empty mfir object.

  :
  :

Parameter Sets

VERSION:     $Id: mfir.m,v 1.103 2010/05/05 09:30:07 ingo Exp $

SEE ALSO:    miir, ltpda_filter, ltpda_uoh, ltpda_uo, ltpda_obj, plist

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

click here

Method Report for mfir/mfir

Some information of the method mfir/mfir are listed below:	
Class name	mfir
Method name	mfir
Category	Constructor
CVS Version	$Id: mfir.m,v 1.103 2010/05/05 09:30:07 ingo Exp $
Min input args	0
Max input args	-1
Min output args	1
Max output args	1

Sets for this method ...

Default

Key	Default Value	Options	Description
NAME	'None'	*none*	The name of the constructed FIR filter.
DESCRIPTION	''	*none*	The description of the constructed FIR filter.

back to top

Getting more help

- LTPDA Toolbox has a decent amount of documentation:
  - >> doc ltpda
- Which methods are available?
  - >> methods <class_name>
  - example:

```
>> methods mfir

Methods for class mfir:

Contents            display             mfir                setA                setPlotinfo         update
bsubmit             eq                  ne                  setDescription      setProcinfo         viewHistory
char                get                 rebuild             setHistout          setUUID
copy                impresp             redesign            setIunits           simplifyUnits
created             index               report              setMdlfile          string
creator             isprop              resp                setName             submit
csvexport           isvalid             save                setOunits           type
```

Setting object properties

- Properties of an object can be set using ‘setter’ methods, or during construction:

```
>> a = ao(plist('name', 'bob'))
----------- ao 01: bob -----------

       name: bob
       data: None
       hist: ao / ao / $Id: ao.m,v 1.315 2010/06/25 13:55:38 ingo Exp $
    mdlfile: empty
description:
       UUID: 500458d6-2a4d-42a9-8d25-3fe5ebd1548f
------------------------------------
```

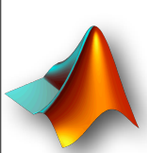
```
>> a = ao;
>> a.setName('bob')
----------- ao 01: bob -----------

       name: bob
       data: None
       hist: ltpda_uoh / setName / $Id: setName.m,v 1.12 2010/06/07 16:35:26
ingo Exp $
    mdlfile: empty
description:
       UUID: 7172543d-e69d-4fcf-abdd-b111b9c16434
------------------------------------
```

Modifying or copying...

- Many methods can be used to modify existing objects; some methods create new objects
- Modifying:
  - `>> a.setName('bob')`
    - the object 'a' will be modified and its name changed
- Copying:
  - `>> b = a.setName('bob')`
    - object 'a' will be copied. The copy will get the name 'bob' and 'a' will be left intact

- Some methods can not be used as modifiers



Help!

- Which properties does an object have?

- >> properties <class_name>
- >> properties(object)

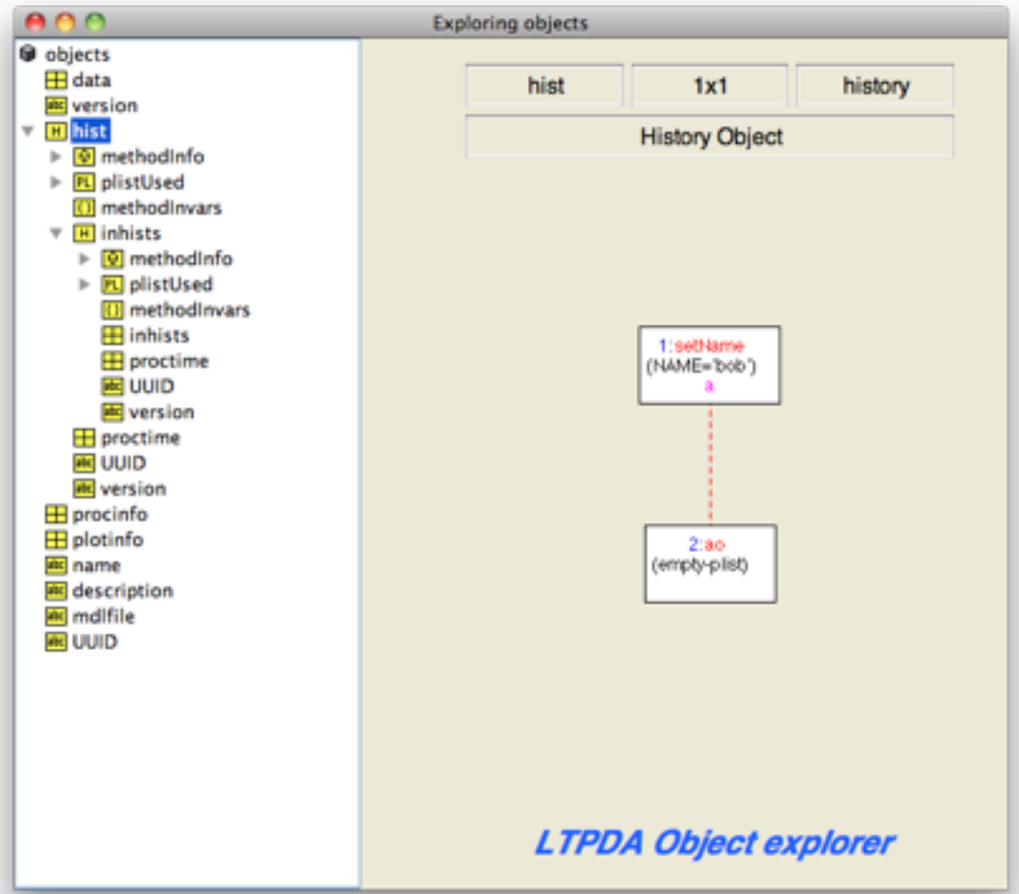
Note: some properties are read-only. You need to check for the existence of a setter method like 'setName'. These methods take care of the history for you!

Viewing history

- We have two static ‘viewers’:
  - using graphviz (recall the introduction)
    - outputs vector graphics so can be used for huge history trees
  - using matlab
    - suitable for small history trees only

- Use graphical explorer
  - >> ltpda_explorer(obj)

- Look at the commands:
  - >> type(obj)



Viewing history

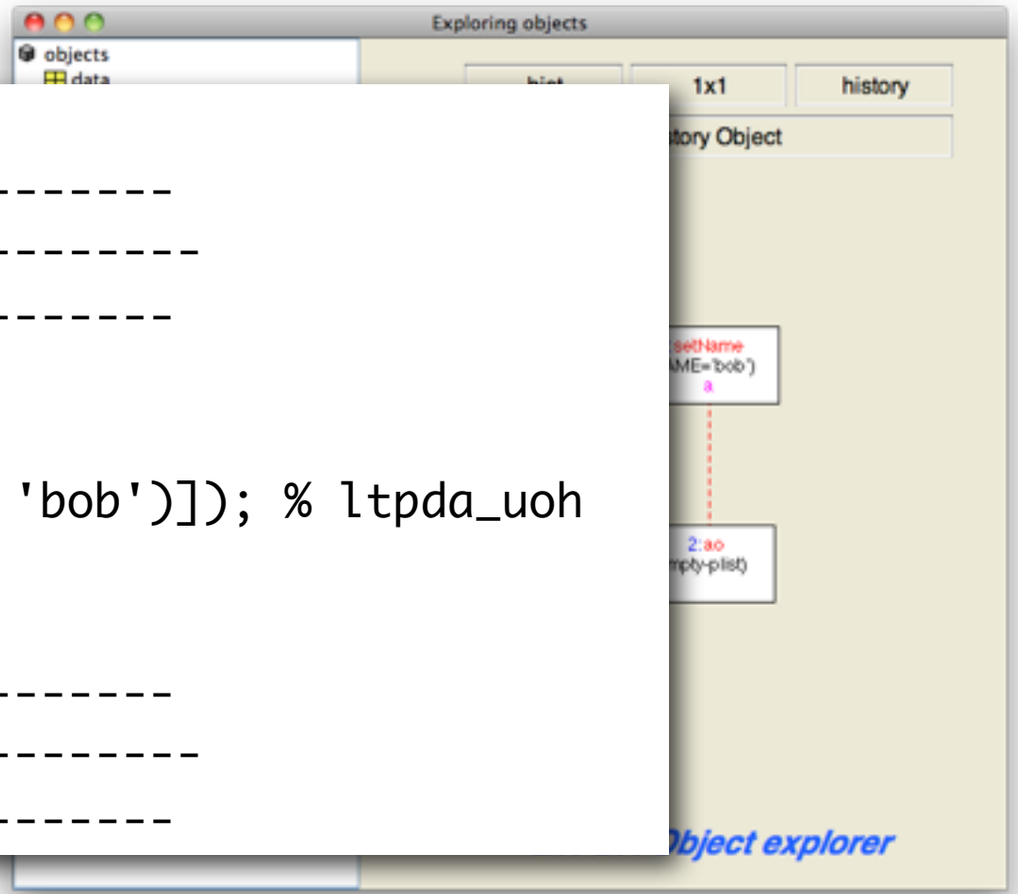
- We have two static ‘viewers’:
  - using graphviz (recall the introduction)
    - outputs vector graphics so can be used for huge history trees
  - using matlab
    - suitable for small history trees only

- Use
  - >
- Loc
  - >

```
>> type(a)
------------------------------------------------
------------------------bob-----------------------
------------------------------------------------

a2812886 = ao([plist()]); % ao
a2818295 = setName(a2812886, [plist('NAME', 'bob')]); % ltpda_uoh
a_out = a2818295;

------------------------------------------------
------------------------bob-----------------------
------------------------------------------------
```



Build a time-series AO

- AOs can contain different types of data
  - Time-series data are stored in a `tsdata` object
  - In this case, the `ao.data` field will be a `tsdata` object
  - They also have properties:

tsdata	
t0	Absolute time-stamp of first sample
xunits	X-axis units
yunits	Y-axis units

- Constructors:
  - `a = ao(vector, sample_rate)`
  - `a = ao(plist('tsfcn', 't.^2 + t', 'fs', 10, 'nsecs', 1000))`
  - others: `>> help ao`, click ‘Parameter Sets’

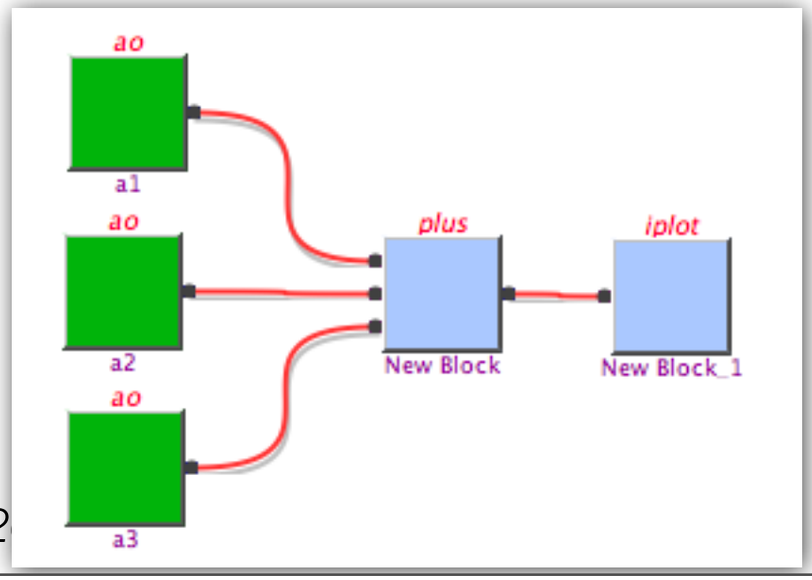
Basic Math

- You can operate on AOs using a large set of methods
  - In particular, many typical Math operations are available (overloaded)
    - Further details at: http://www.lisa.aei-hannover.de/ltpda/documents/files/operator_rules.pdf

```
a = ao(1);
b = ao(2);
c = a+b
```

```
a = ao(2);
a.^2
```

```
a = [ao(1) ao(2) ao(3)];
b = ao(4);
c = a + b
```



Saving and loading objects

- All LTPDA User Objects can be saved to (and loaded from), file in
  - XML format
  - binary MAT format

```
>> save(a, 'foo.xml')
>> save(a, 'foo.mat')
>> a.save(plist('filename', 'foo.xml'))
>> b = ao('foo.xml')
>> c = ao('foo.mat')
>> d = ao(plist('filename', 'foo.xml'))
```

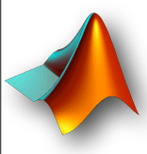
```
<?xml version="1.0" encoding="utf-8"?>
<ltpda_object ltpda_version="2.0 (R2008b)">
   <object shape="1x1" type="ao">
      <property prop_name="data" shape="1x1" type="fsdata">
         <object shape="1x1" type="fsdata">
            <property prop_name="t0" shape="1x1" type="time">
               <object shape="1x1" type="time">
                  <property prop_name="utc_epoch_milli" shape="1x1"
                  <property prop_name="timezone" shape="1x1" type="s
                  <property prop_name="timeformat" shape="1x23" type
                  <property prop_name="time_str" shape="0x0" type="c
                  <property prop_name="version" shape="1x53" type="c
               </object>
            </property>
            <property prop_name="navs" shape="1x1" type="double">1</
            <property prop_name="fs" shape="1x1" type="double">1000<
            <property prop_name="enbw" shape="1x1" type="double">0.2
            <property prop_name="version" shape="1x55" type="char">$
            <property prop_name="xunits" shape="1x1" type="unit">
               <object shape="1x1" type="unit">
                  <property prop_name="strs" shape="1x1" type="cell"
```

Reading existing data files

- You can construct AOs from existing ASCII (raw) data files

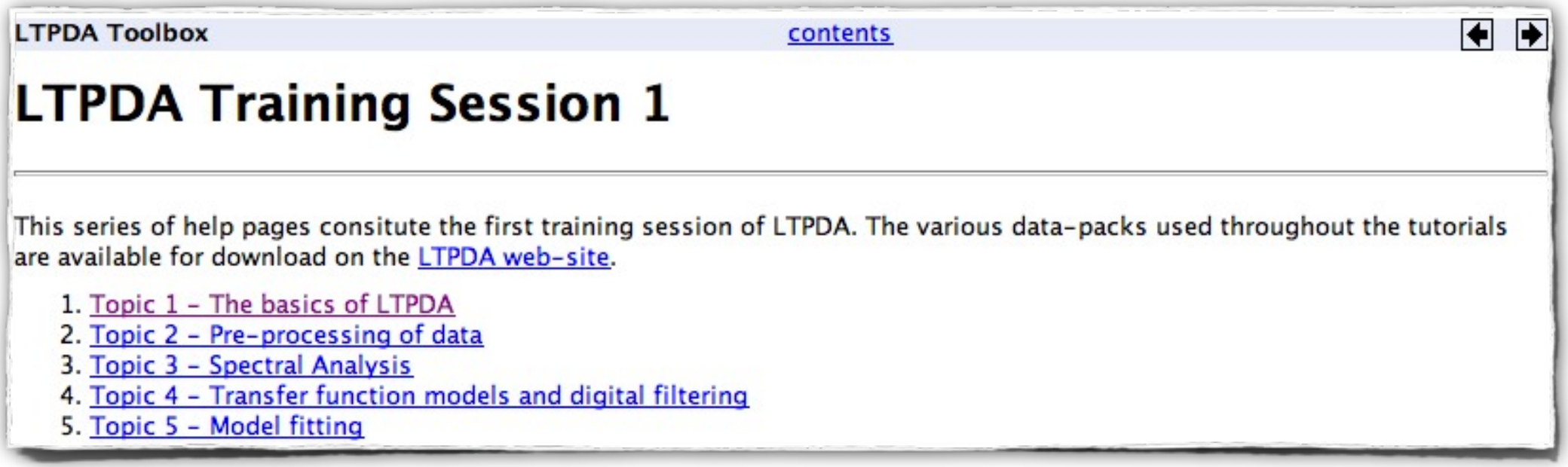
```
a = ao('topic1/simpleASCII.txt')
```

```
sigs = ao(plist('filename', 'topic1/multicolumnASCII.txt', ...
                'columns', [1 3 1 5], ...
                'name', {'sin2', 'sin4'}, ...
                'yunits', {'m', 'm'}, ...
                'description', {'sine wave at 2Hz', 'sine wave at 4Hz'}))
```



Hands on the keys...

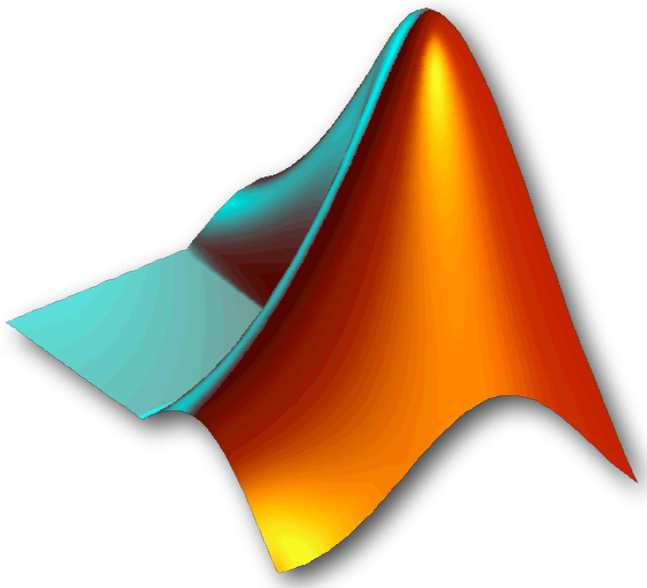
- You can work through these concepts in the relevant section of the documentation
  - "LTPDA Training Session 1"

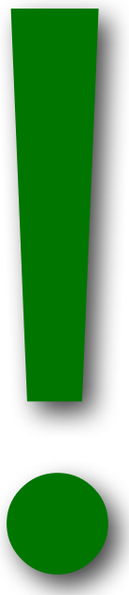

LTPDA Toolbox contents

LTPDA Training Session 1

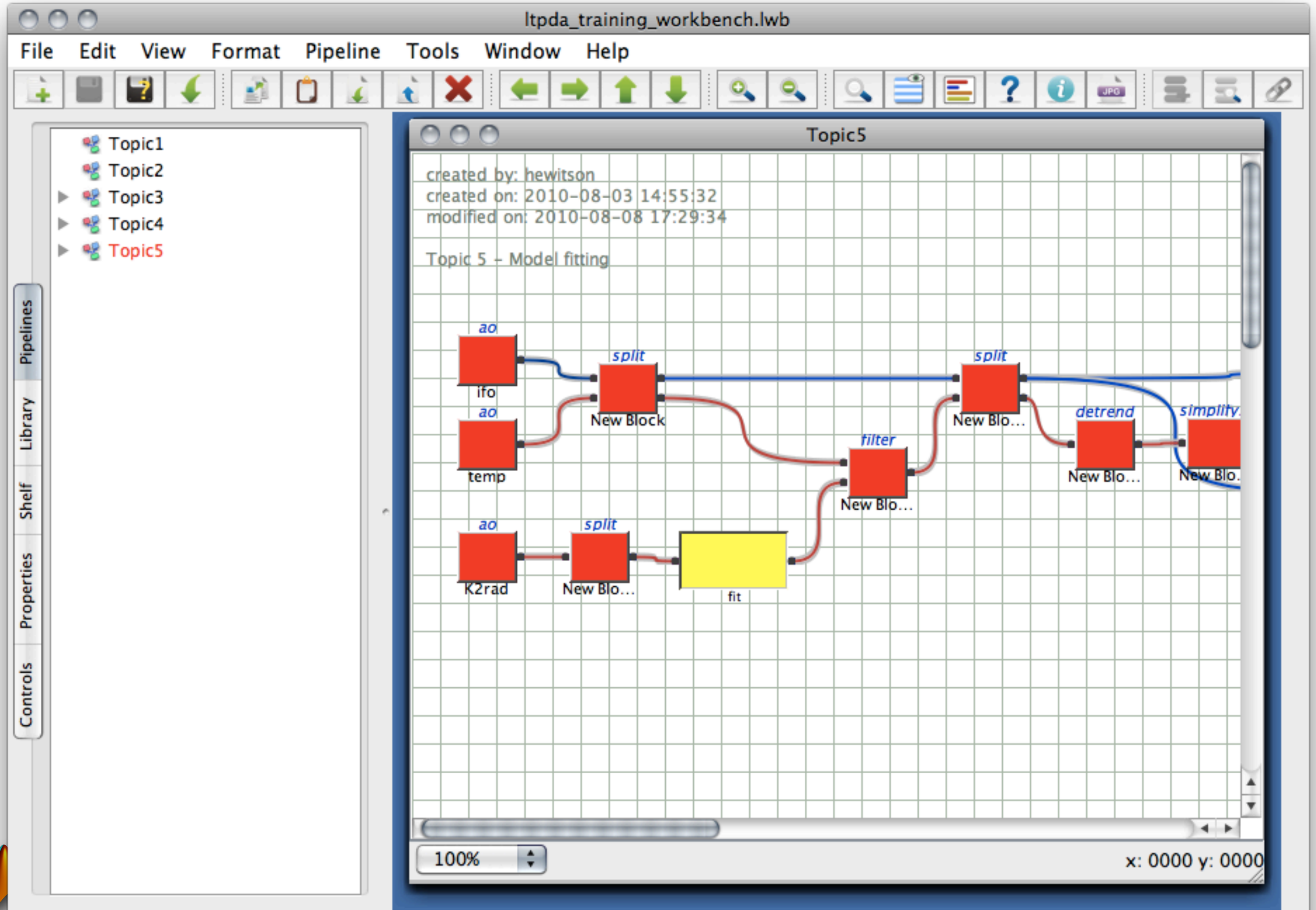
This series of help pages consitute the first training session of LTPDA. The various data-packs used throughout the tutorials are available for download on the LTPDA web-site.

1. Topic 1 - The basics of LTPDA
2. Topic 2 - Pre-processing of data
3. Topic 3 - Spectral Analysis
4. Topic 4 - Transfer function models and digital filtering
5. Topic 5 - Model fitting





Introducing the workbench



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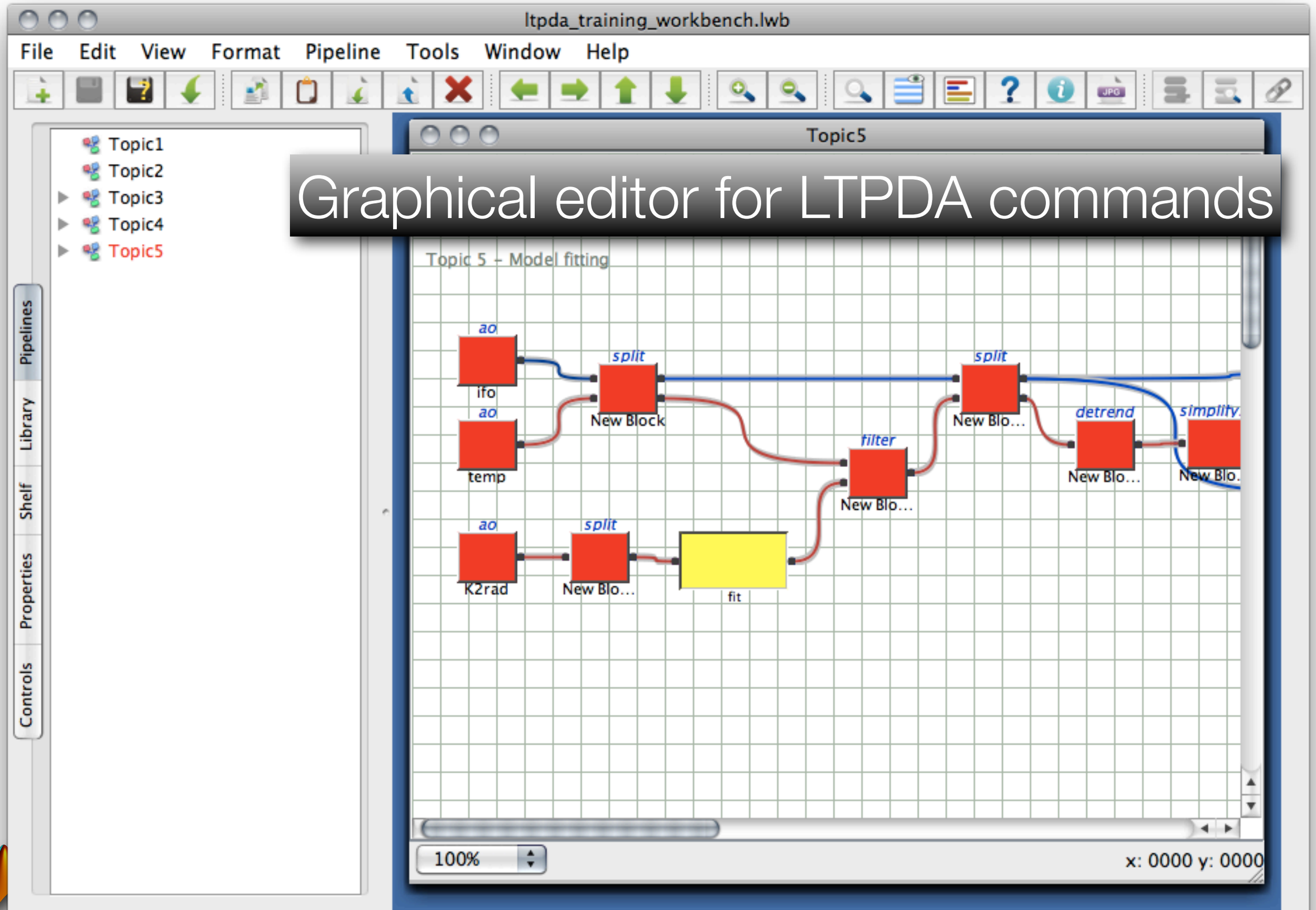
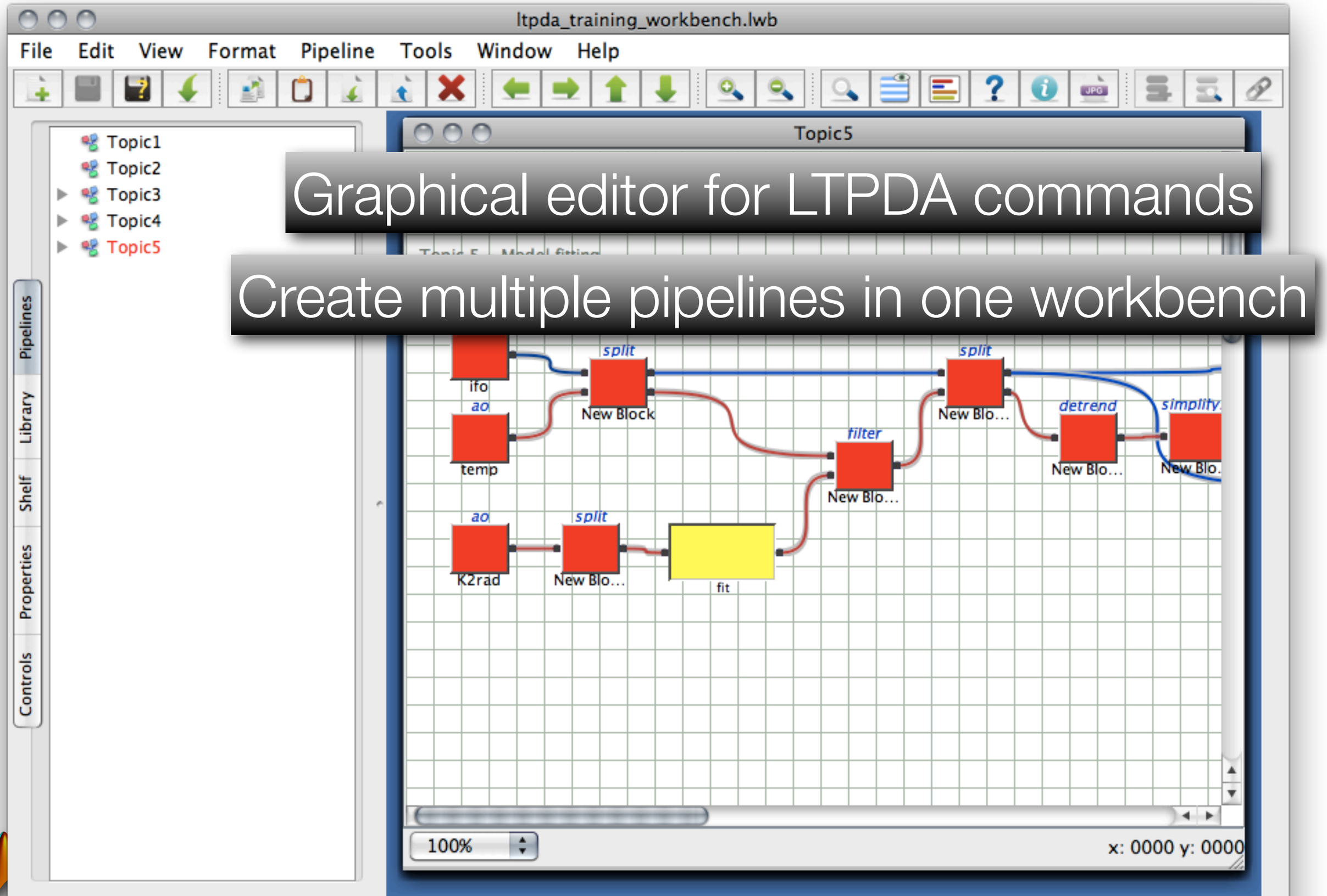


Introducing the workbench



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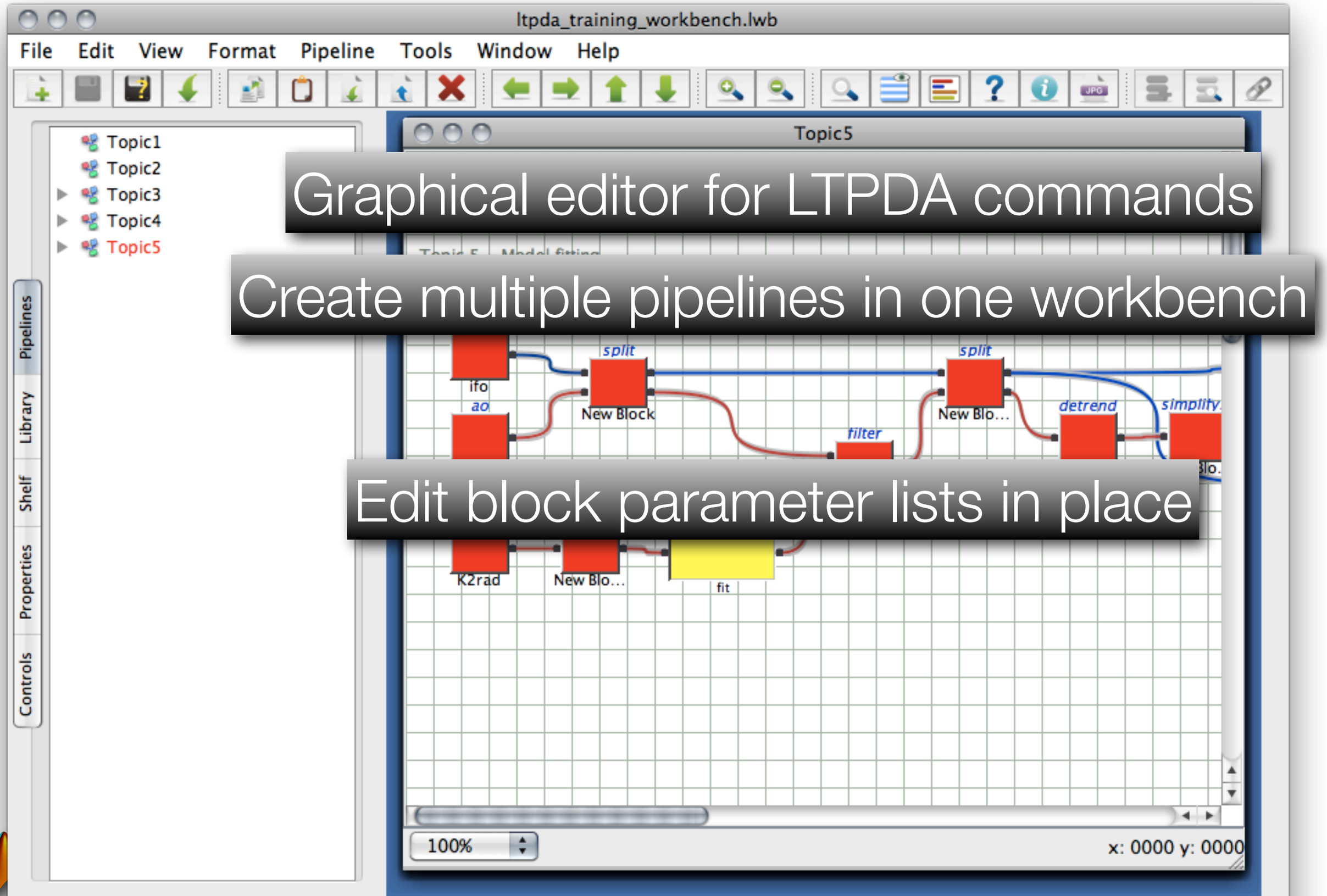

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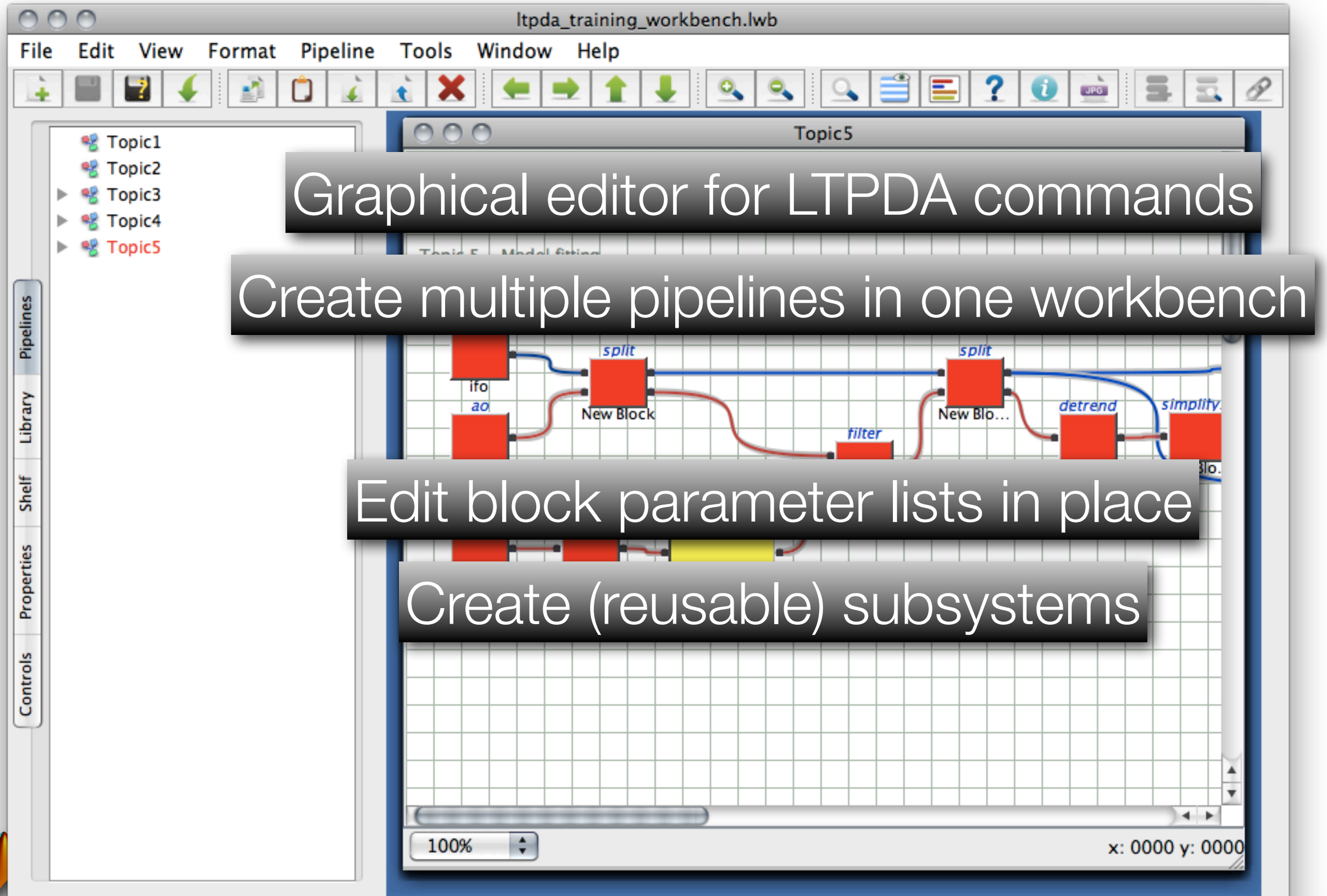

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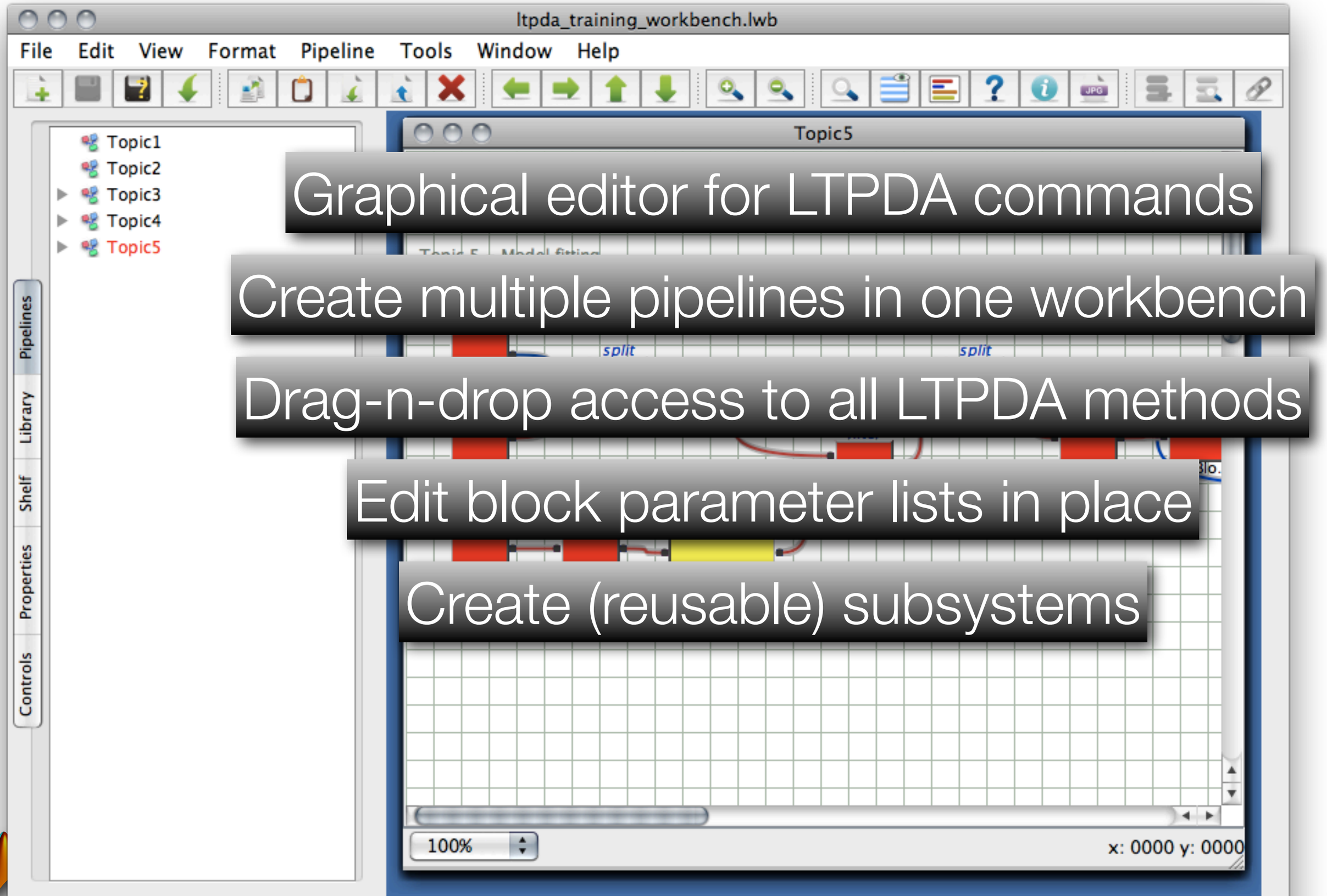
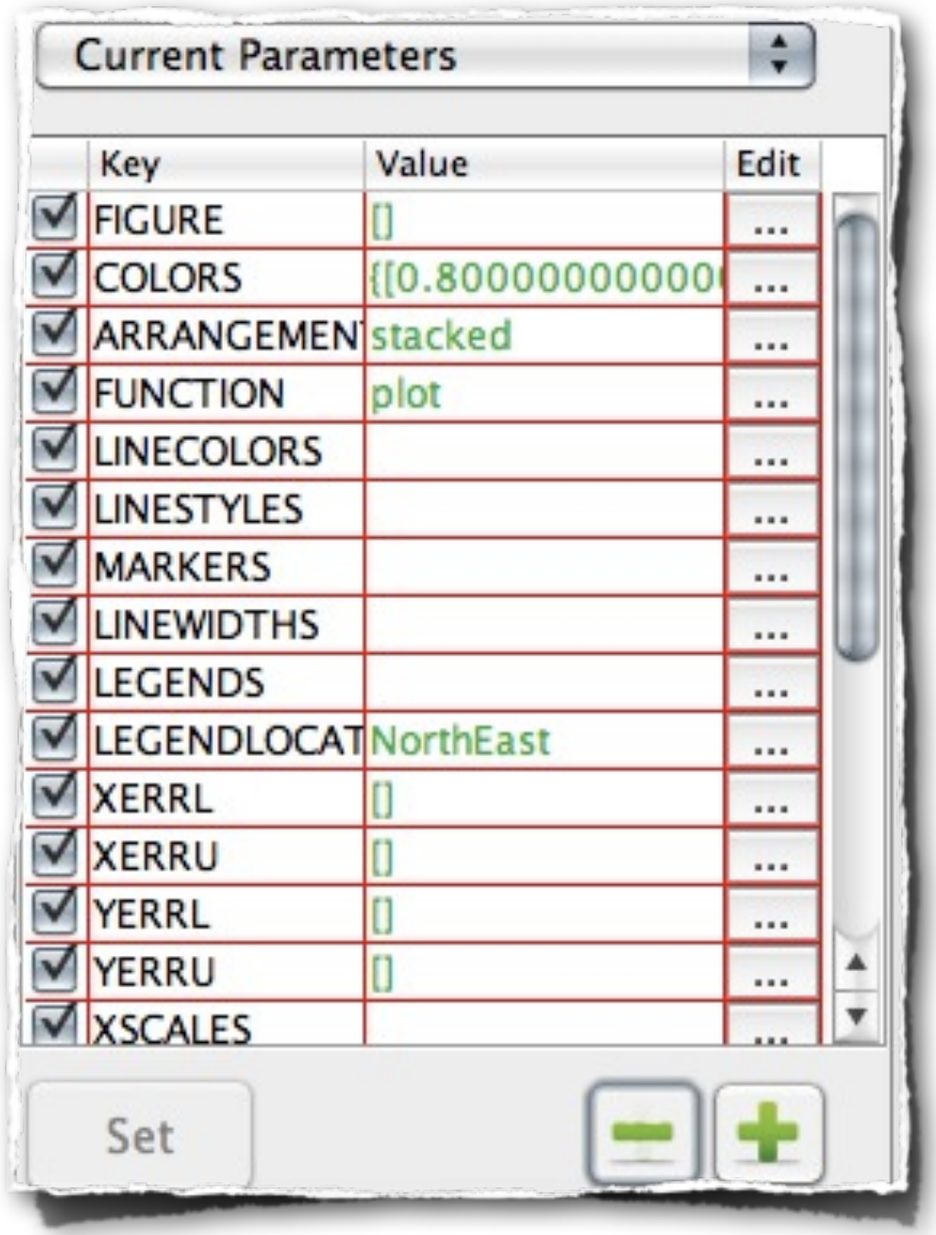
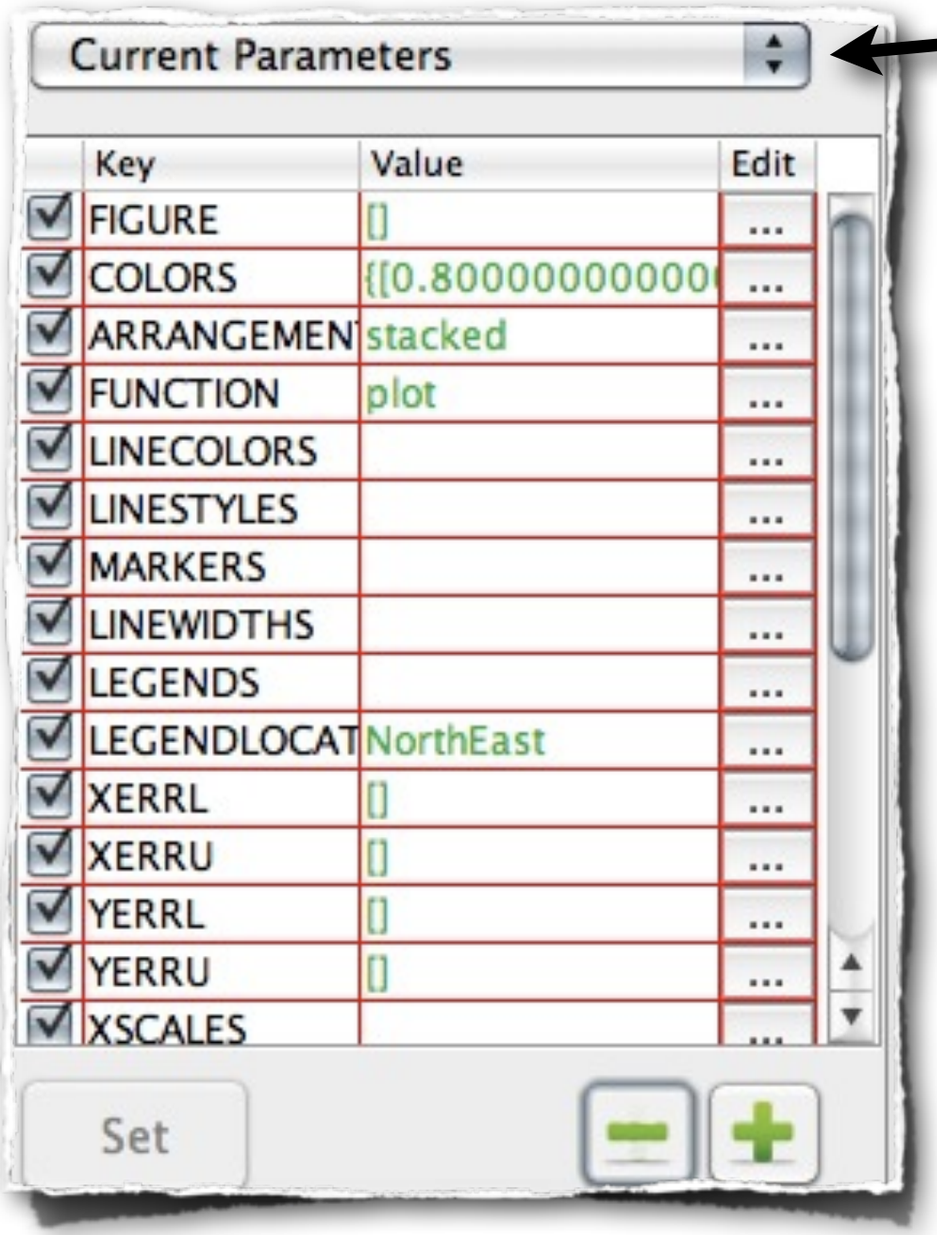


Parameter list editing

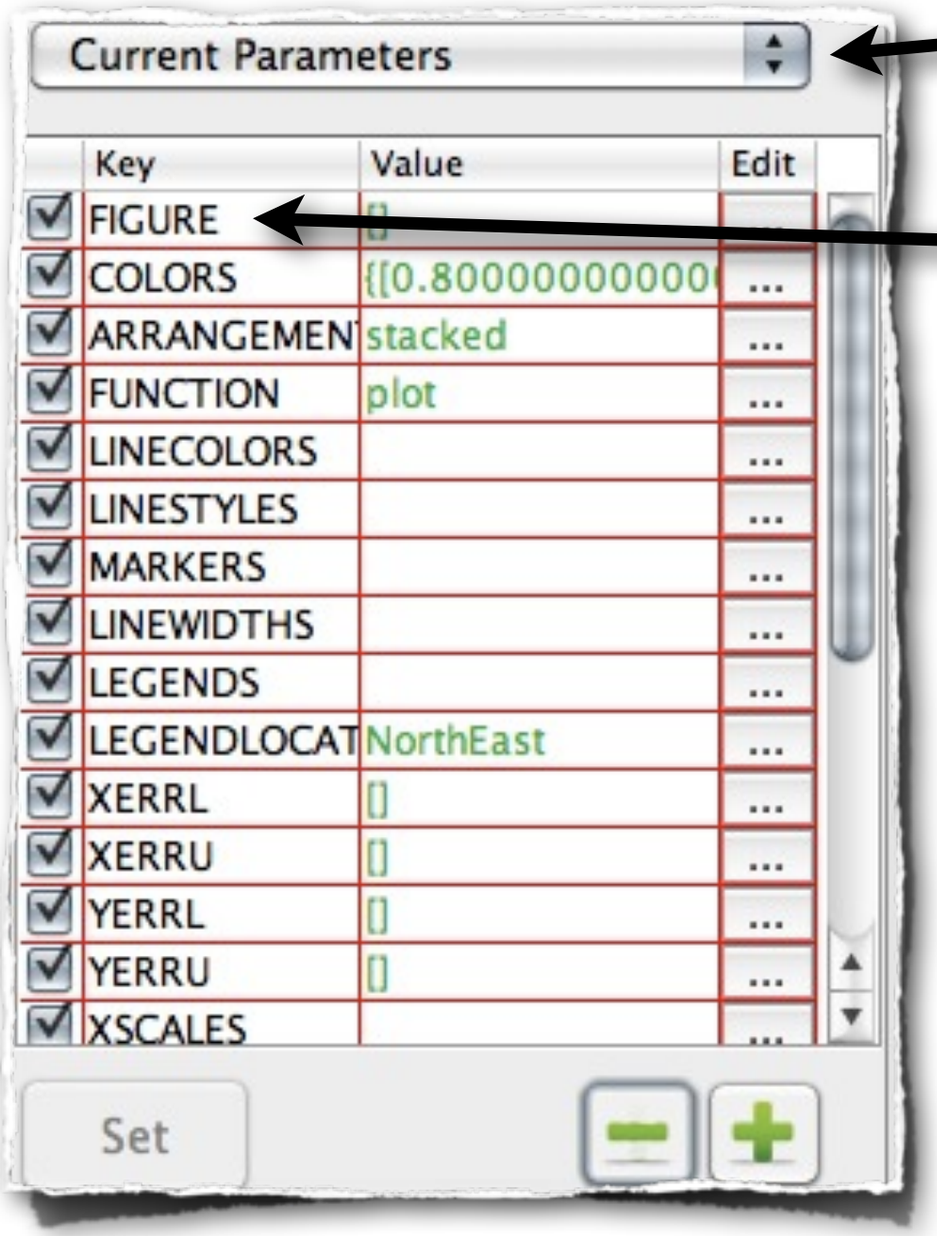


Parameter list editing



Different parameter sets

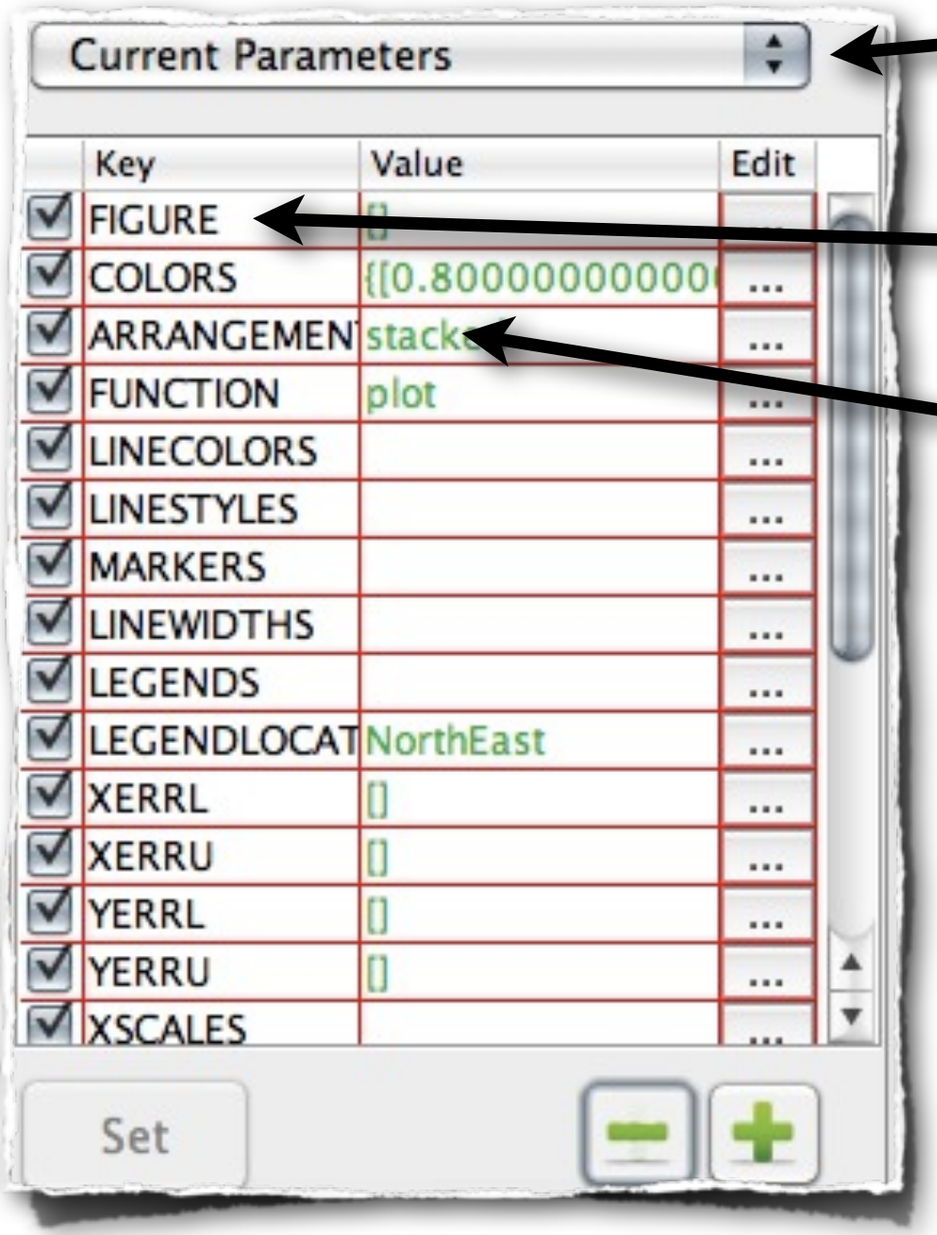
Parameter list editing



Different parameter sets

Parameter ‘key’

Parameter list editing

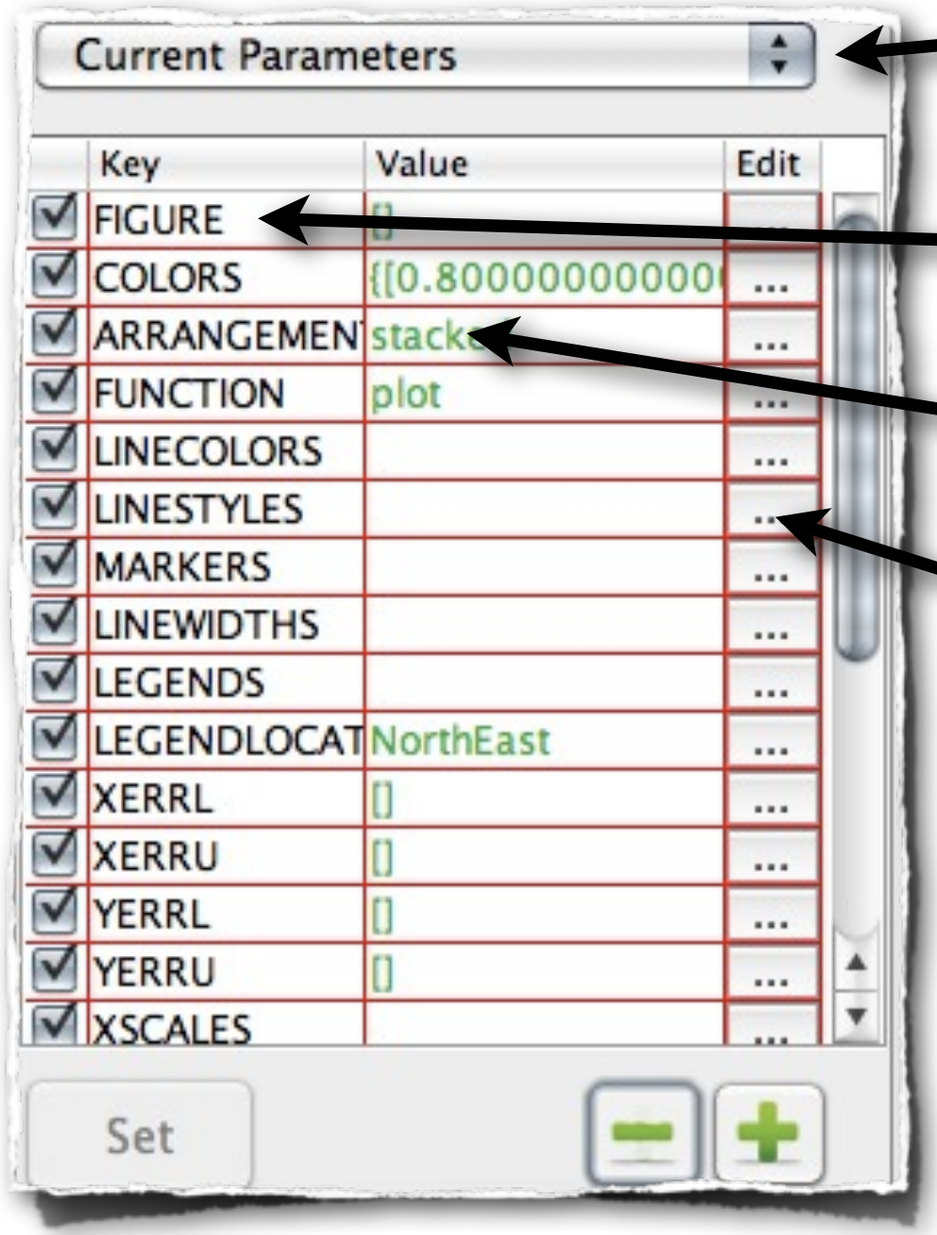


Different parameter sets

Parameter ‘key’

Parameter ‘value’

Parameter list editing



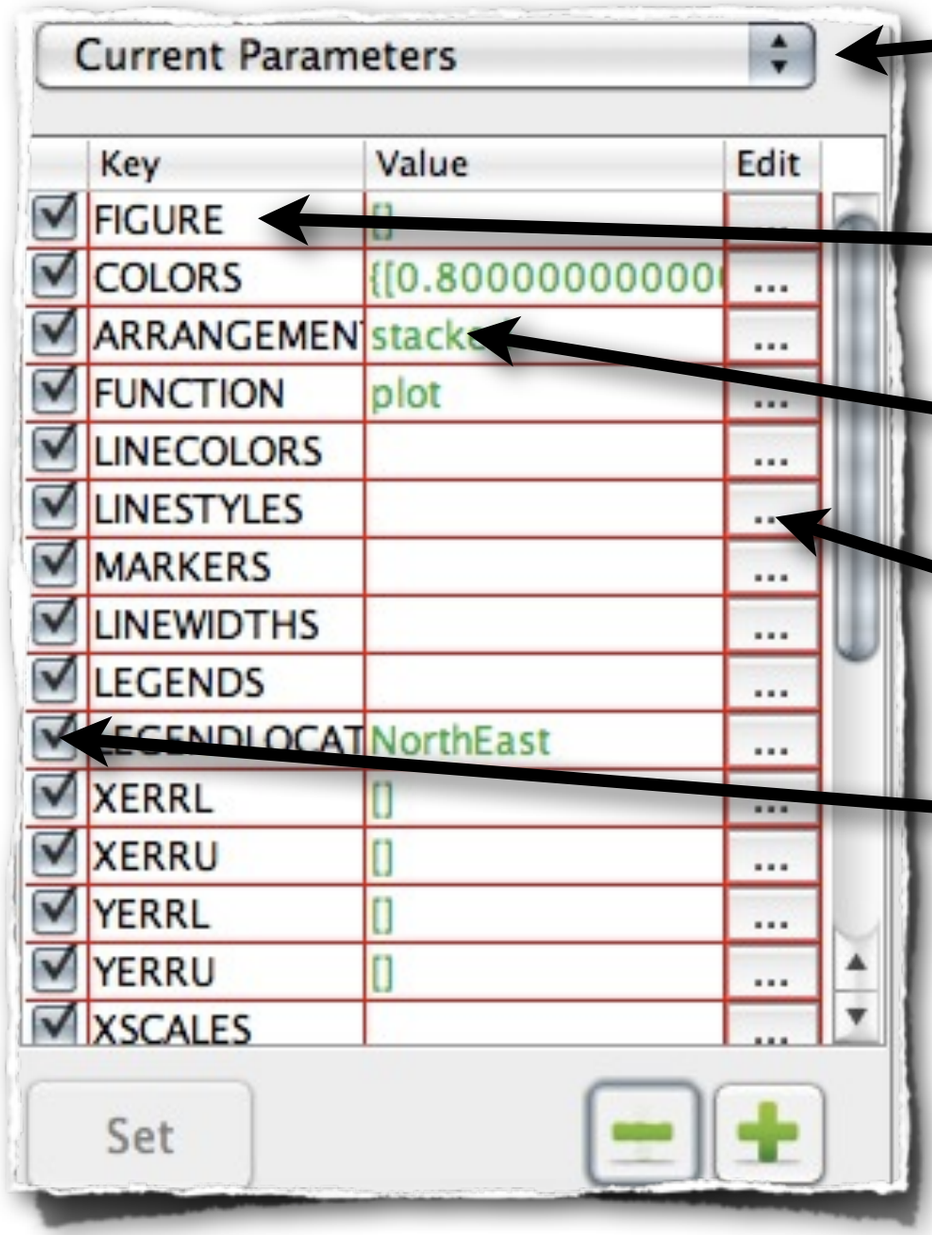
Different parameter sets

Parameter ‘key’

Parameter ‘value’

Open ‘special’ editor

Parameter list editing



Different parameter sets

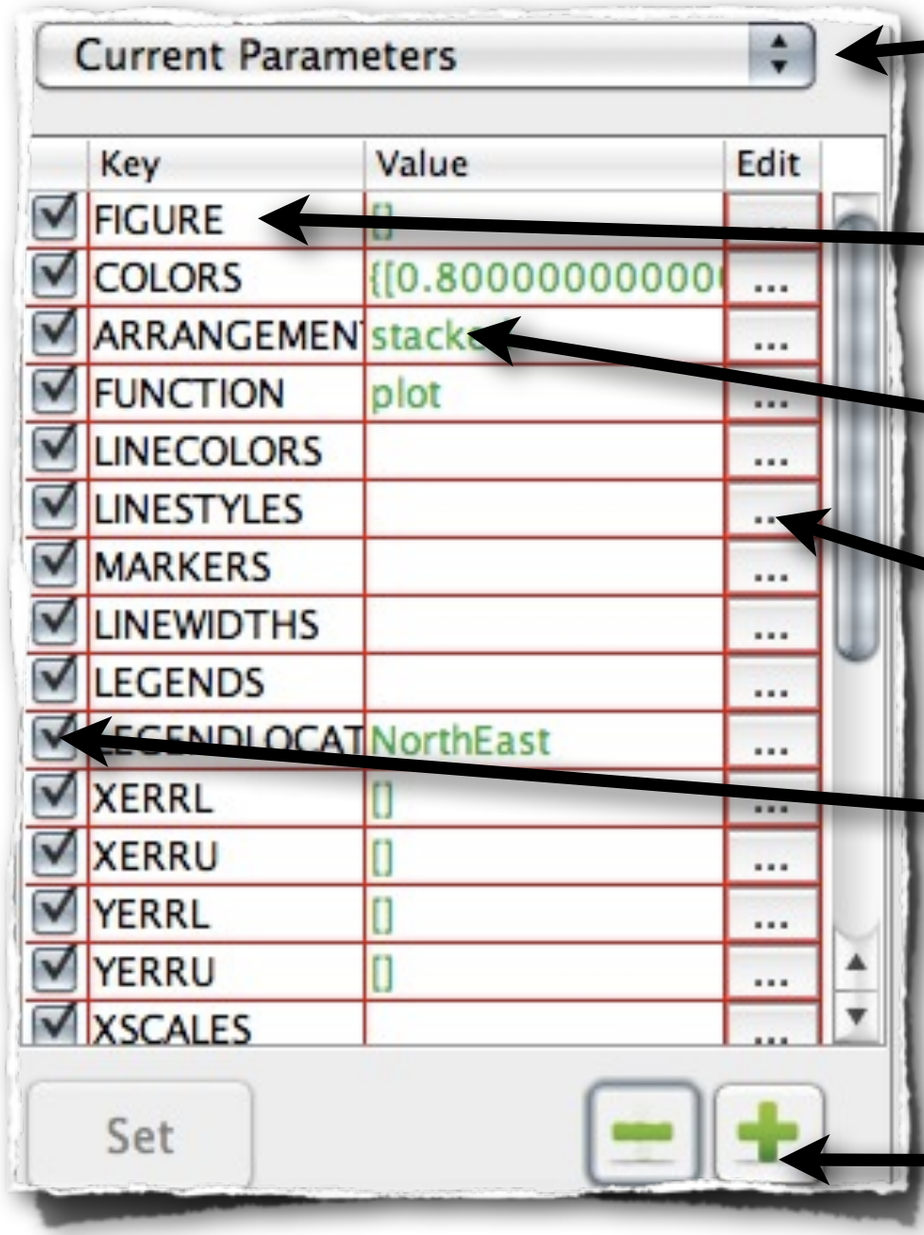
Parameter ‘key’

Parameter ‘value’

Open ‘special’ editor

Activate/de-activate a parameter

Parameter list editing



Different parameter sets

Parameter ‘key’

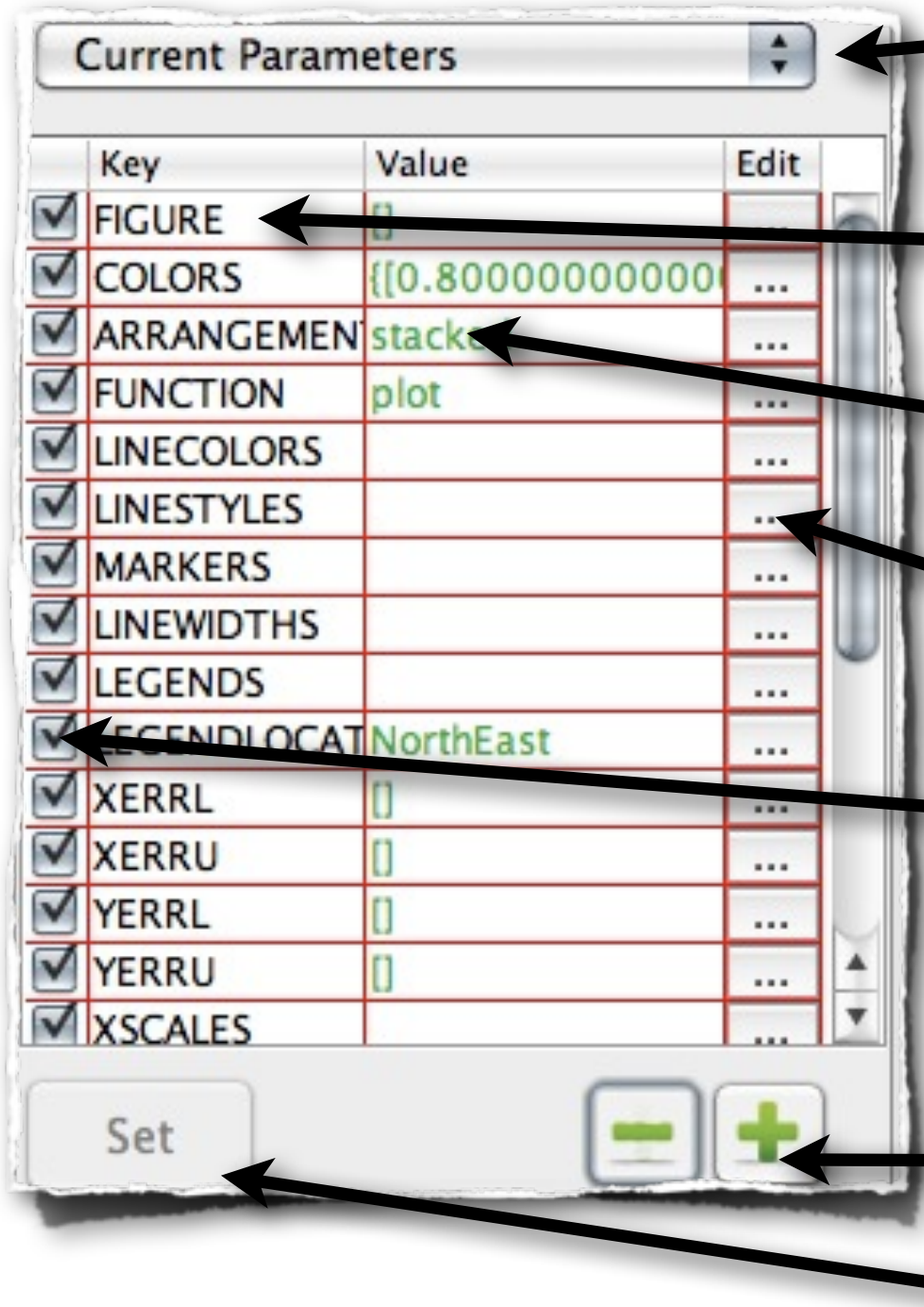
Parameter ‘value’

Open ‘special’ editor

Activate/de-activate a parameter

Add/remove a parameter

Parameter list editing



Different parameter sets

Parameter ‘key’

Parameter ‘value’

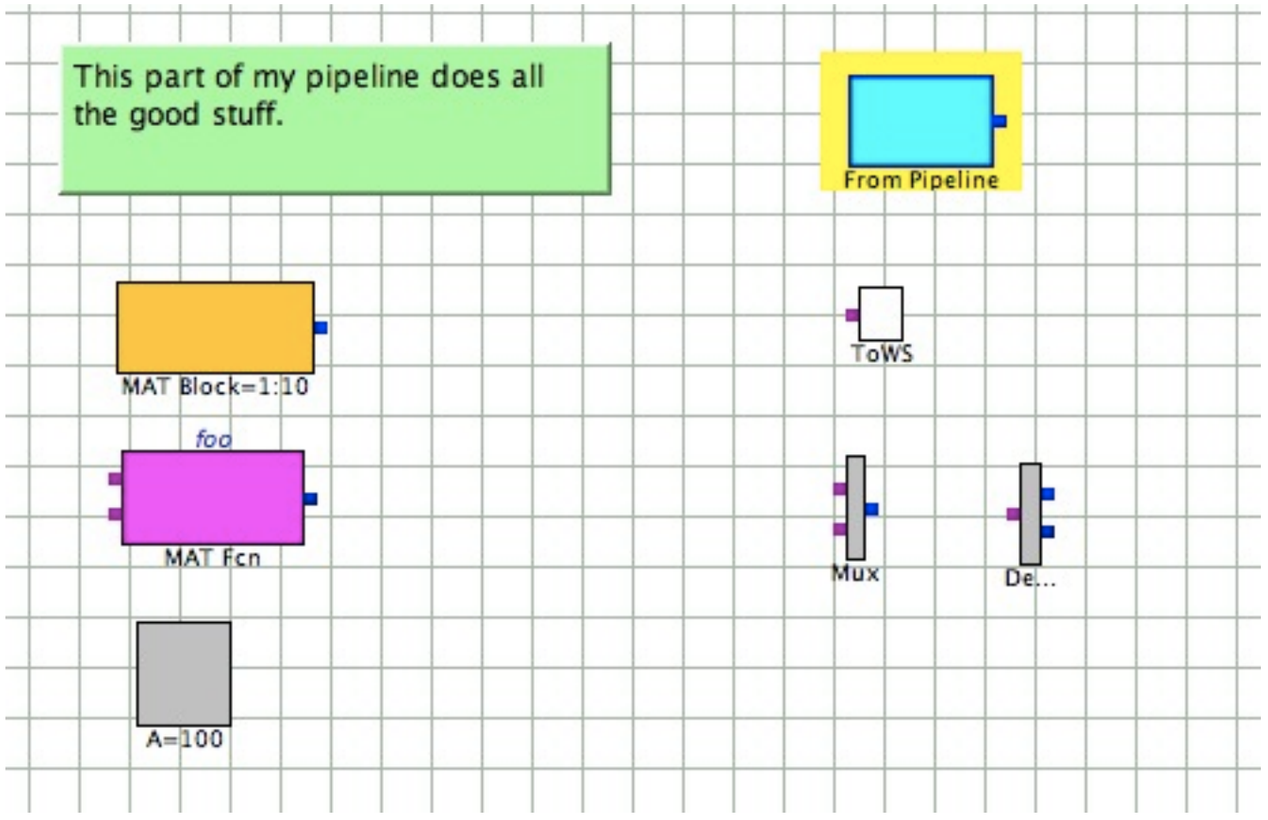
Open ‘special’ editor

Activate/de-activate a parameter

Add/remove a parameter

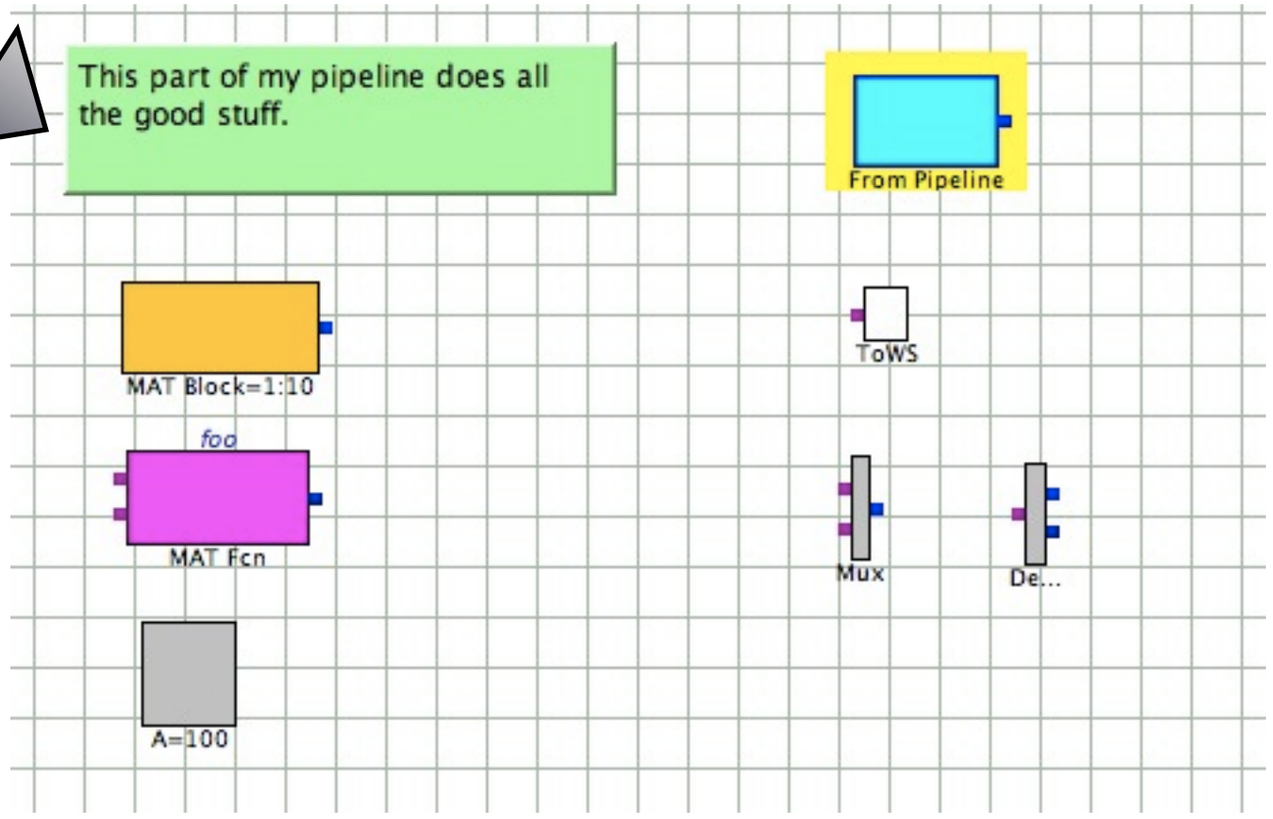
‘Set’ a parameter set

Special blocks



Special blocks

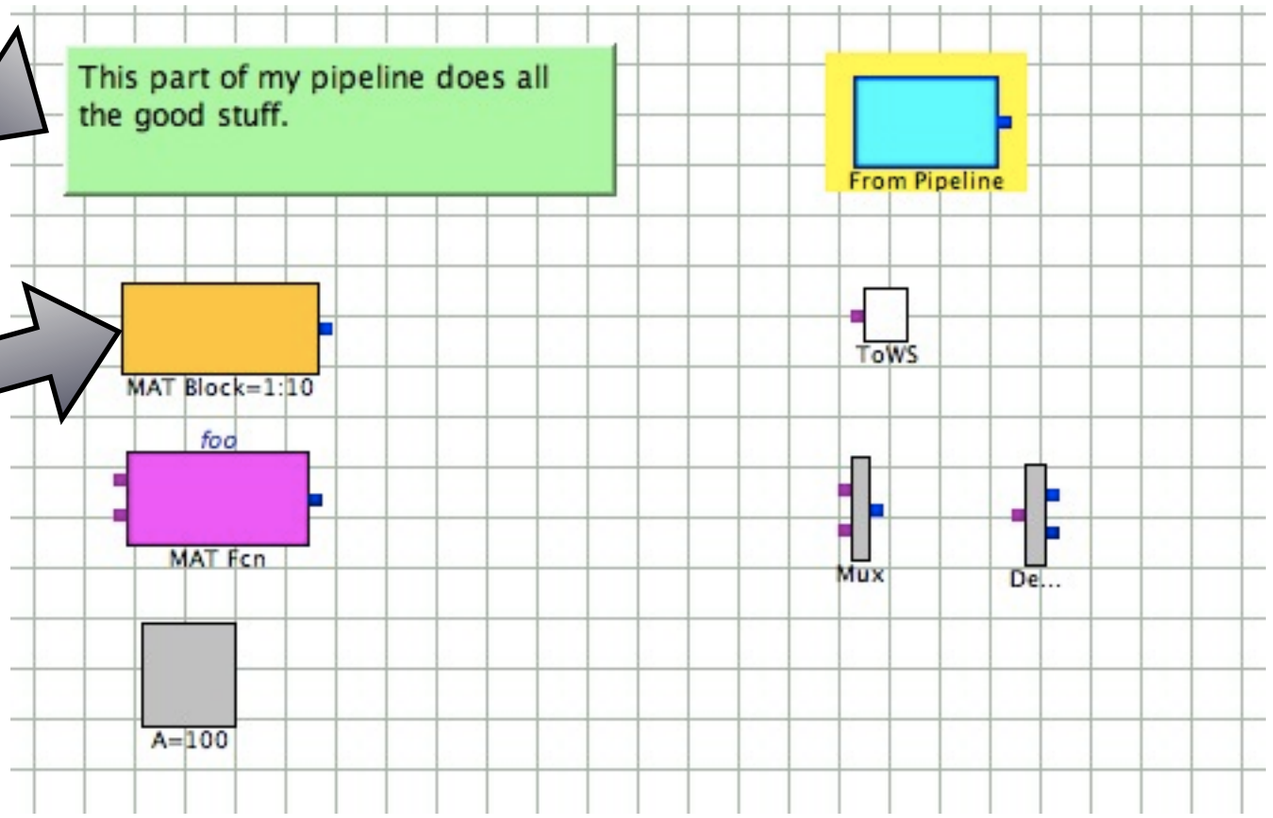
Annotation



Special blocks

Annotation

MATLAB Expressions

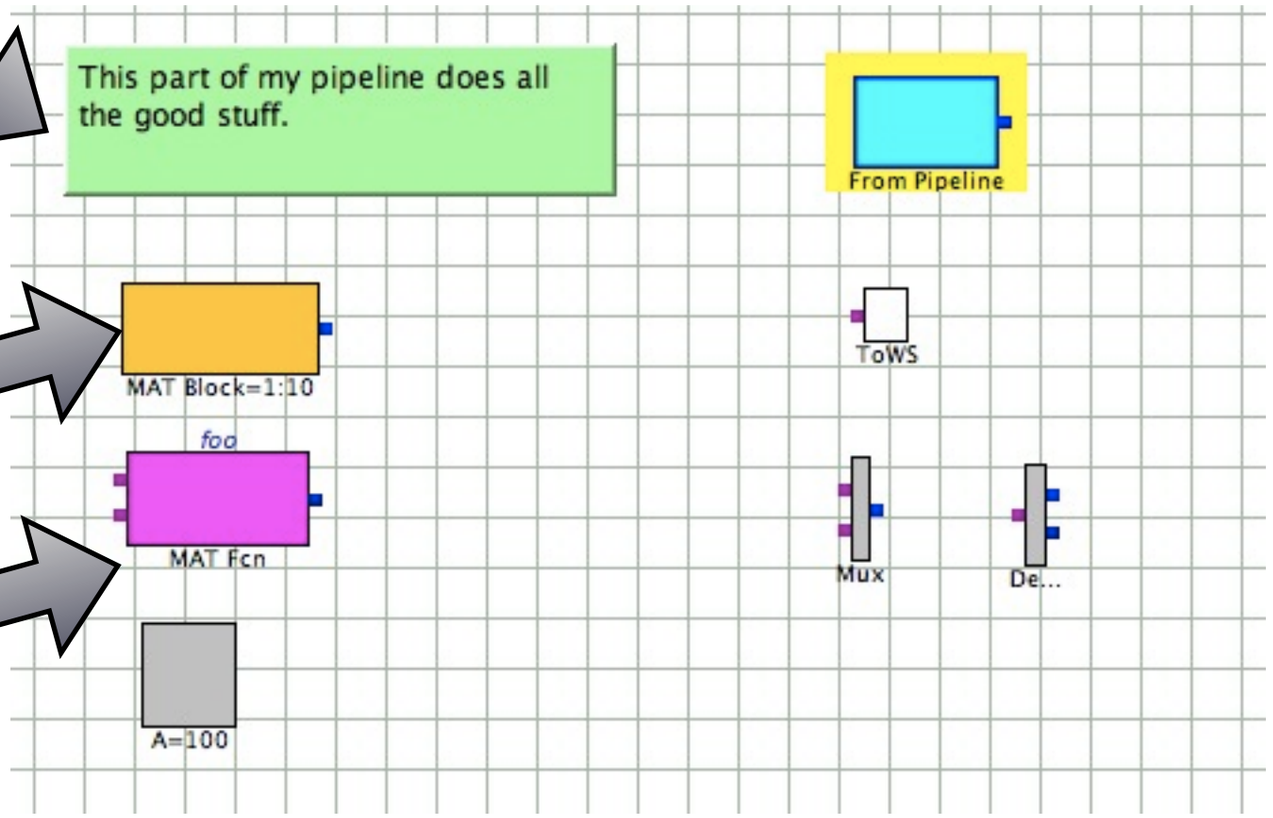


Special blocks

Annotation

MATLAB Expressions

MATLAB Function



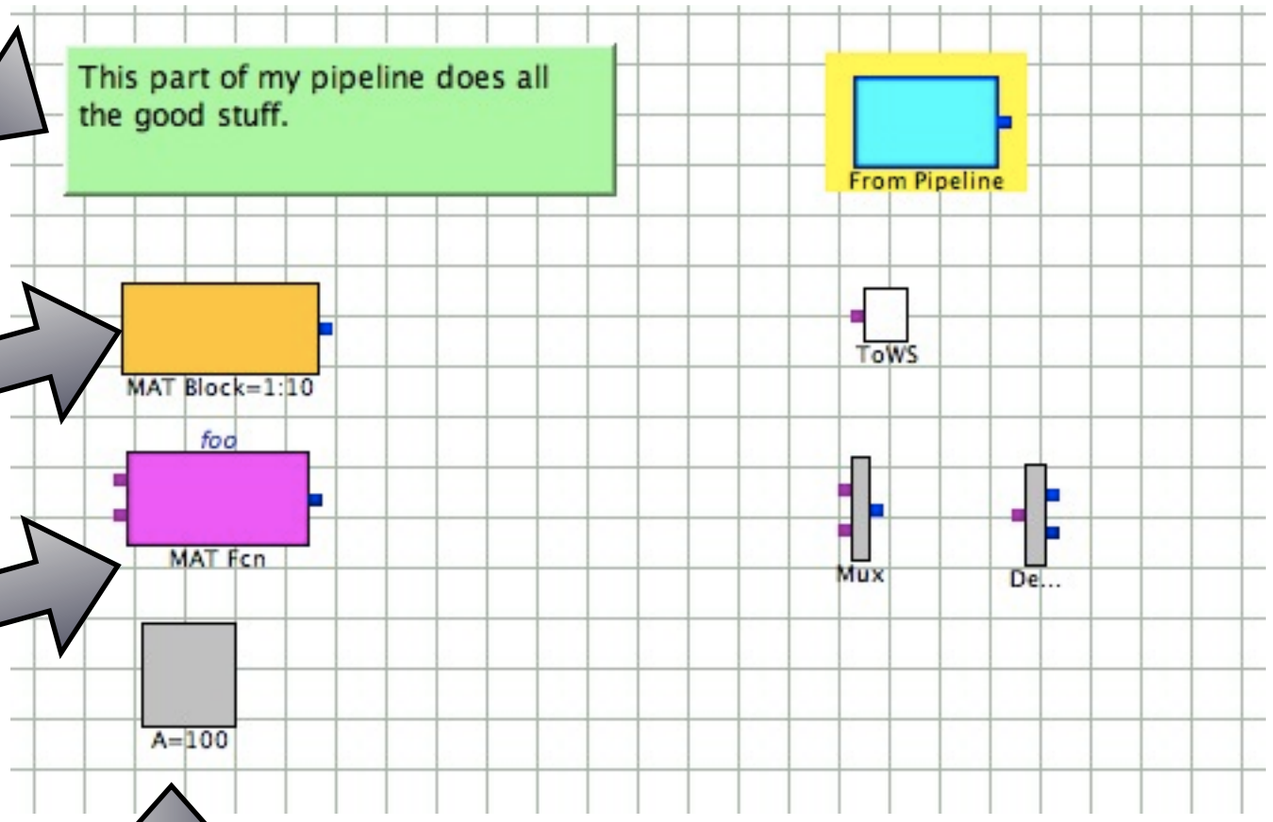
Special blocks

Annotation

MATLAB Expressions

MATLAB Function

Constant



Special blocks

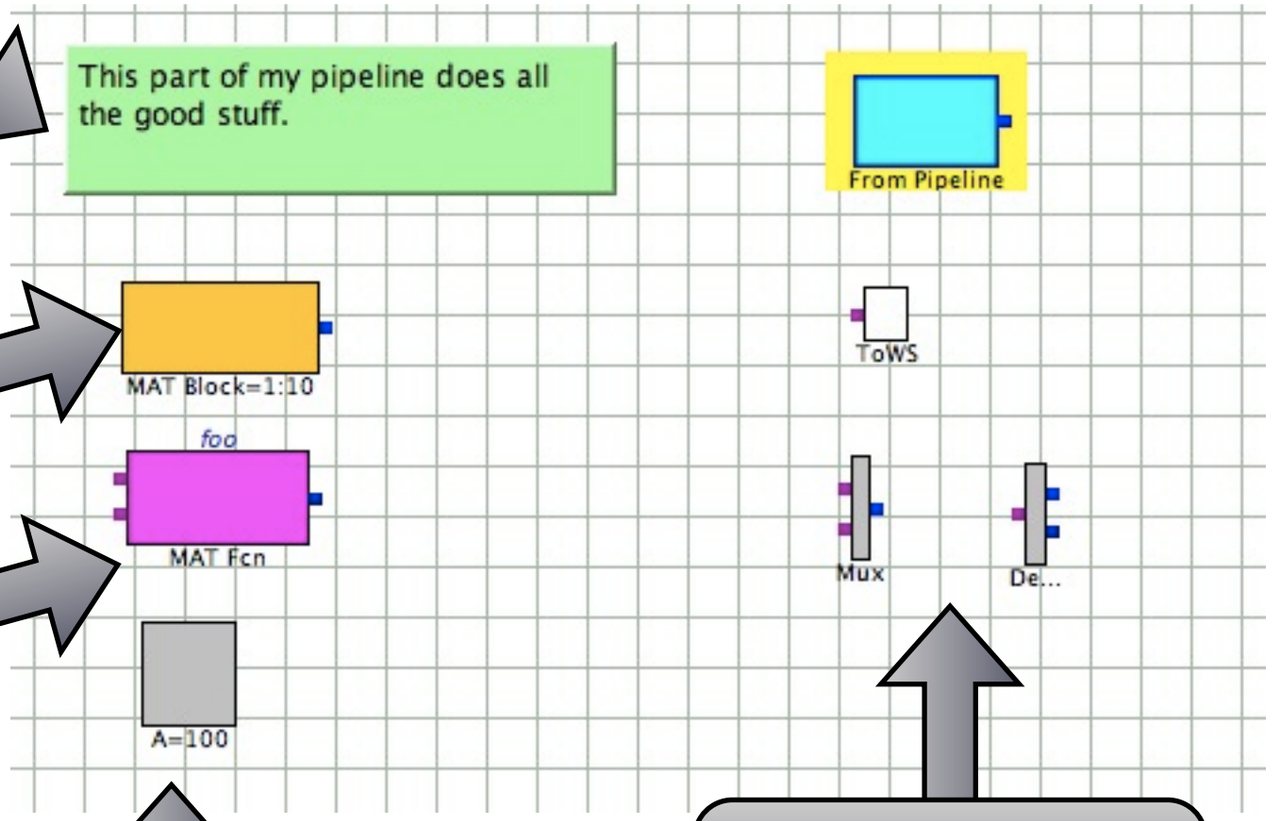
Annotation

MATLAB Expressions

MATLAB Function

Constant

Mux/Demux



Special blocks

Annotation

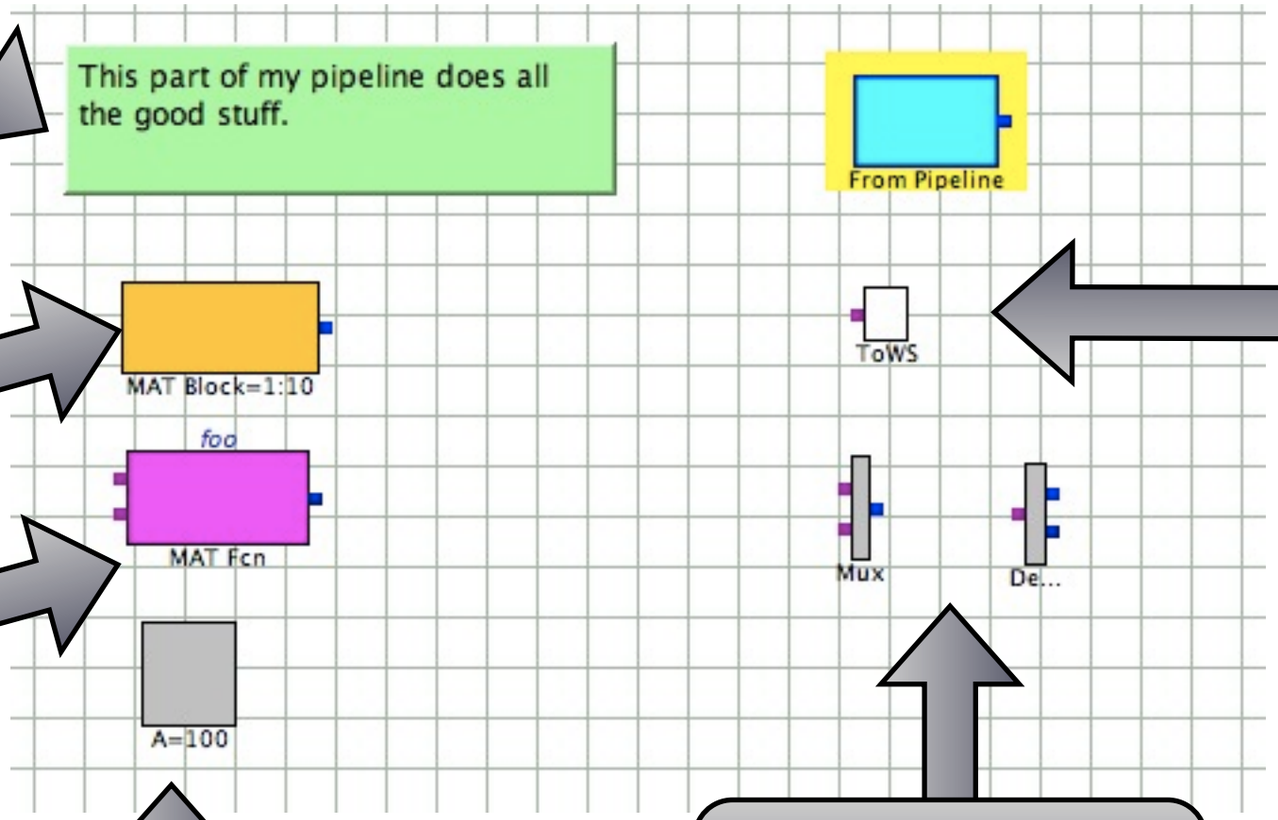
MATLAB Expressions

MATLAB Function

Constant

Export objects to workspace

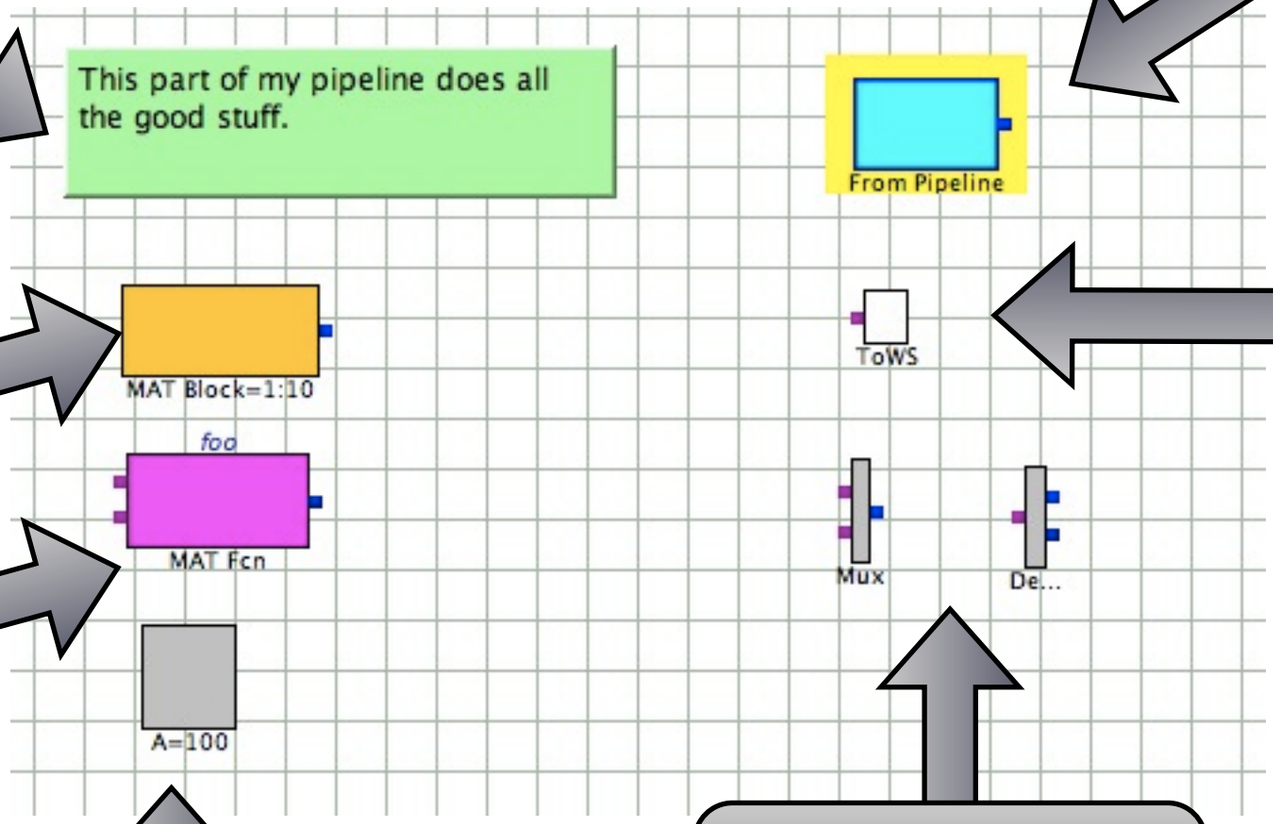
Mux/Demux



Special blocks

Annotation

Import objects from another pipeline



MATLAB Expressions

MATLAB Function

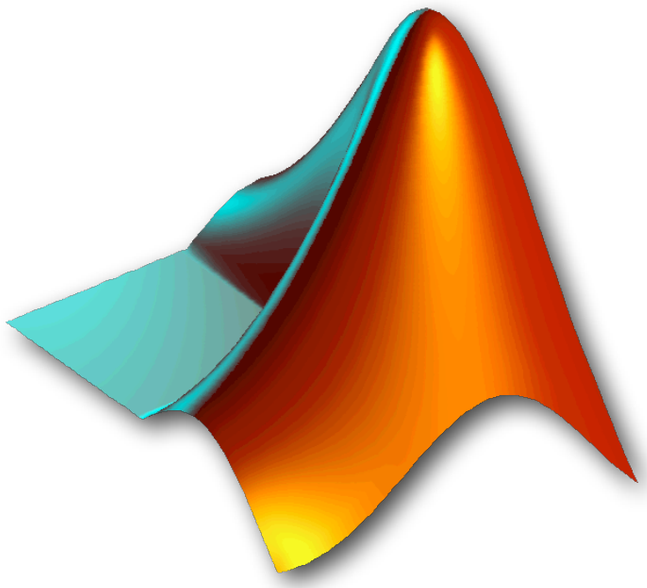
Export objects to workspace

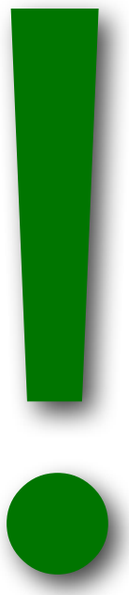
Constant

Mux/Demux

Shortcut keys

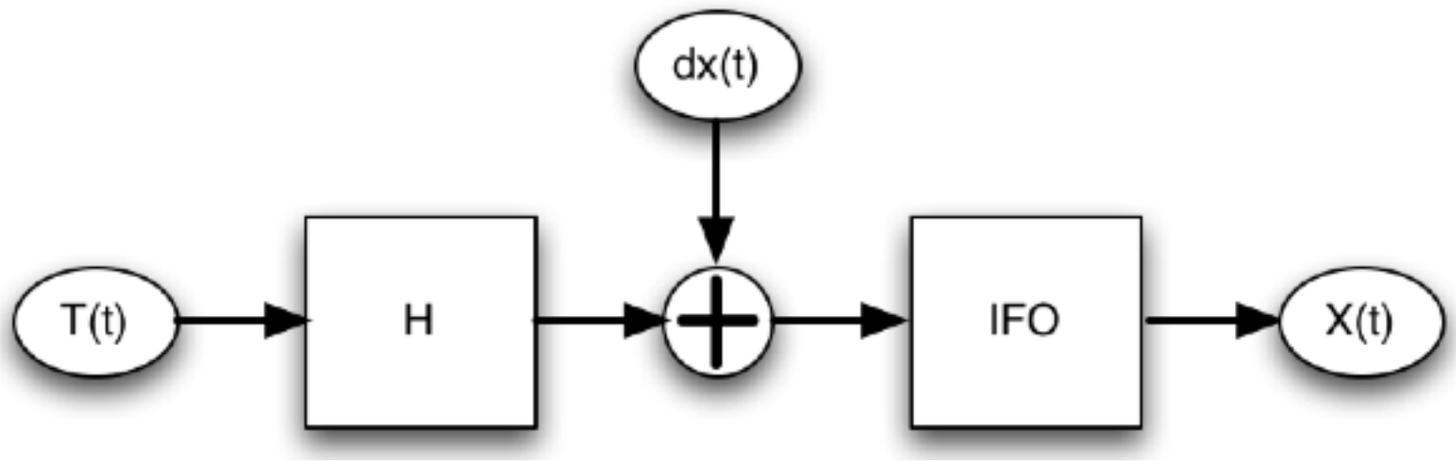
`ctrl-s`	Save workbench
`ctrl-n`	New pipeline in current workbench
`ctrl-c,ctrl-v,ctrl-d`	copy, paste, duplicate
`ctrl-t`	comment-out block(s)
`ctrl-b`	quick-block dialog
`ctrl-i`	edit canvas info
`ctrl-f`	find blocks in workbench
`shift-F1`	help on selected block





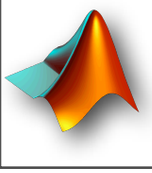
Interferometer-Temperature example

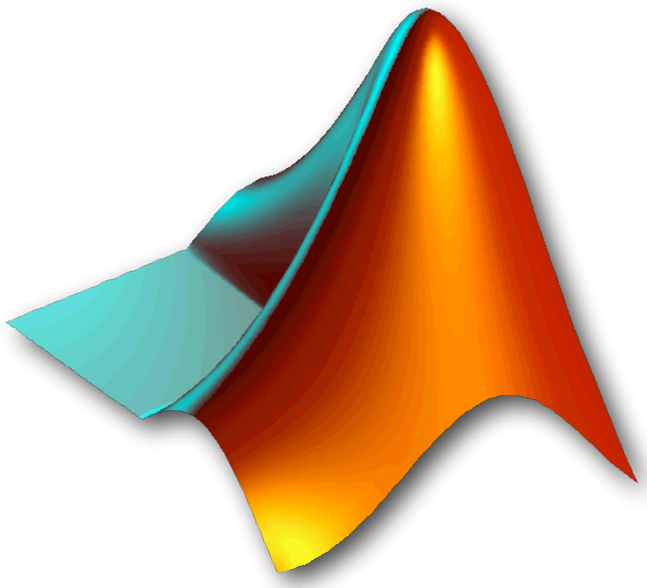
- We have a data analysis exercise which will develop fully over the course of the training session
  - This is the first part: reading and preparing the data
- Work through help section
  - Topic 1
    - IFO/Temperature Example - Introduction

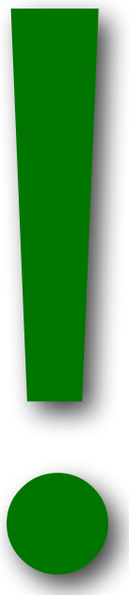


Reading IFO and Temperature data


```
clear all;

%% Read IFO and Temperature data from disk

pl = plist('filepath', 'DataPack/ifo_temp_example', ...
           'columns', [1 2], ...
           'type', 'tsdata');

ifo  = ao(pl.pset('filename', 'ifo_training.dat', ...
                  'yunits', 'rad', ...
                  'name', 'ifo'));
temp = ao(pl.pset('filename', 'temp_training.dat', ...
                  'yunits', 'degC', ...
                  'name', 'temp'));

%% Calibrate IFO data to m

ifo_cal = ifo.scale(plist('factor', 1064e-9/2/pi, 'yunits', 'm/rad'))

%% Calibrate temperature data to K

temp_cal = setYunits(temp + 273.15, 'K')

%% Save calibrated data

save(ifo_cal, 'ifo_disp.mat');
save(temp_cal, 'temp_kelvin.mat');
```





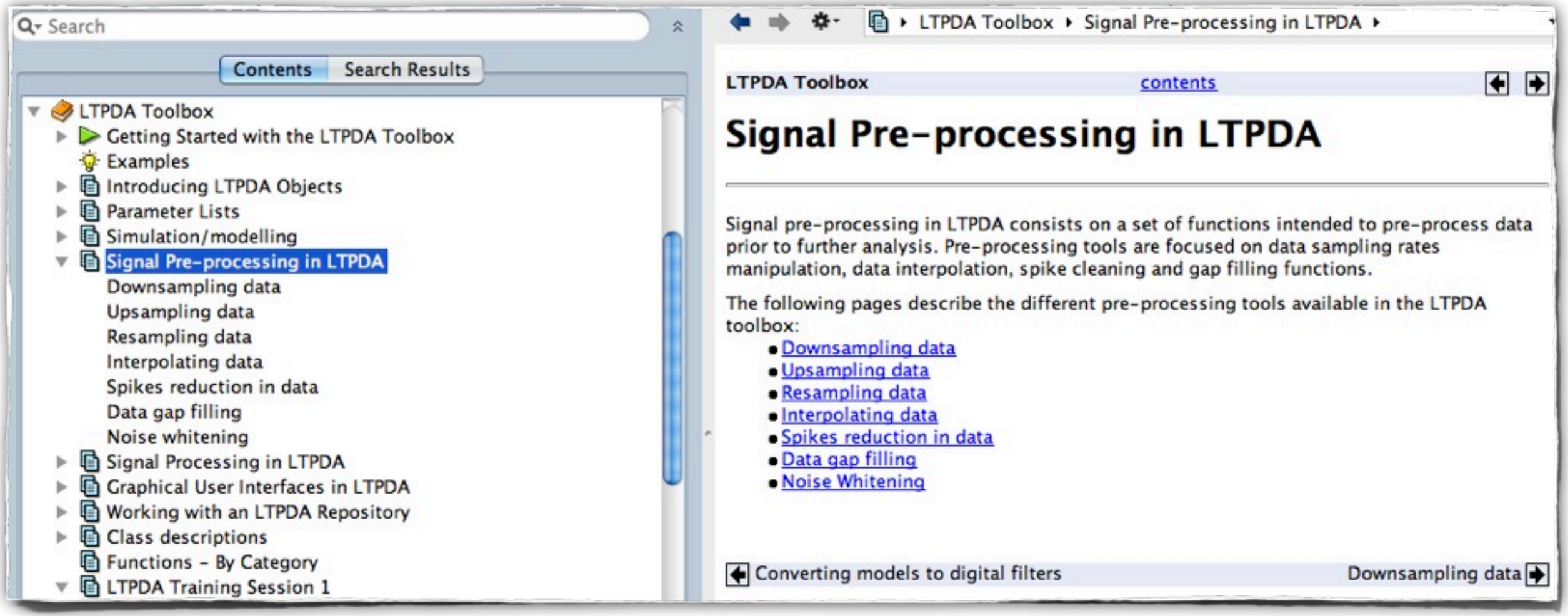


Topic 2: Pre-processing data

- Why?
  - data preparation for further analysis

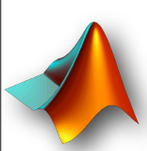
- LTPDA contains a bunch of functions for
  - resampling data
  - interpolation of data
  - de-trending data
  - noise whitening
  - data selection

Look in the help!



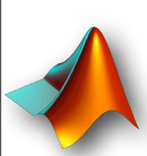
Resampling

- Integer factor
  - Down-sample (`ao/downsample`)
    - for example, to reduce data load
  - Up-sample (`ao/upsample`)
    - for example, to match sample rates, do ‘better’ filtering
- Re-sample (`ao/resample`)
  - fs_out = P/Q * fs_in (P and Q are integers)

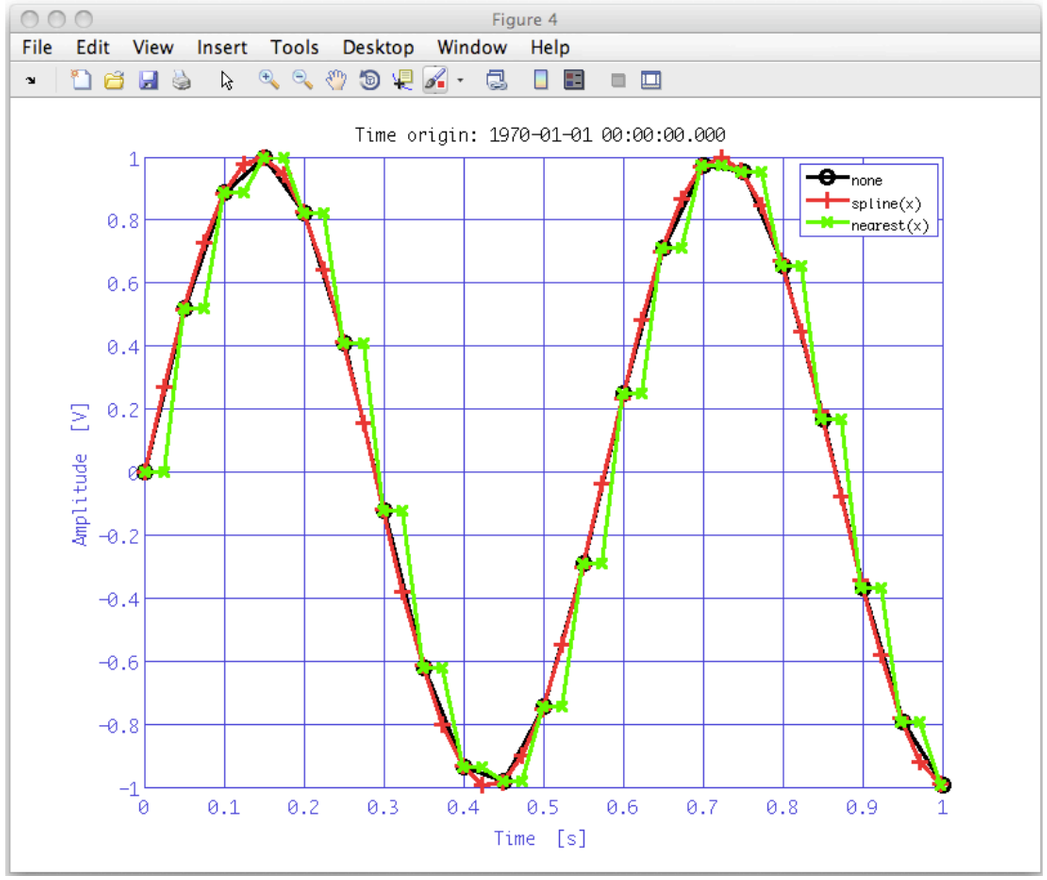


Topic 2 - Exercises 1,2,3

- Open MATLAB documentation
  - In the MATLAB terminal
    - >> doc
  - “Help -> Product Help>”
- work through
  - LTPDA Toolbox - LTPDA Training Session 1 Topic 2
    - Downsampling
    - Upsampling
    - Resampling



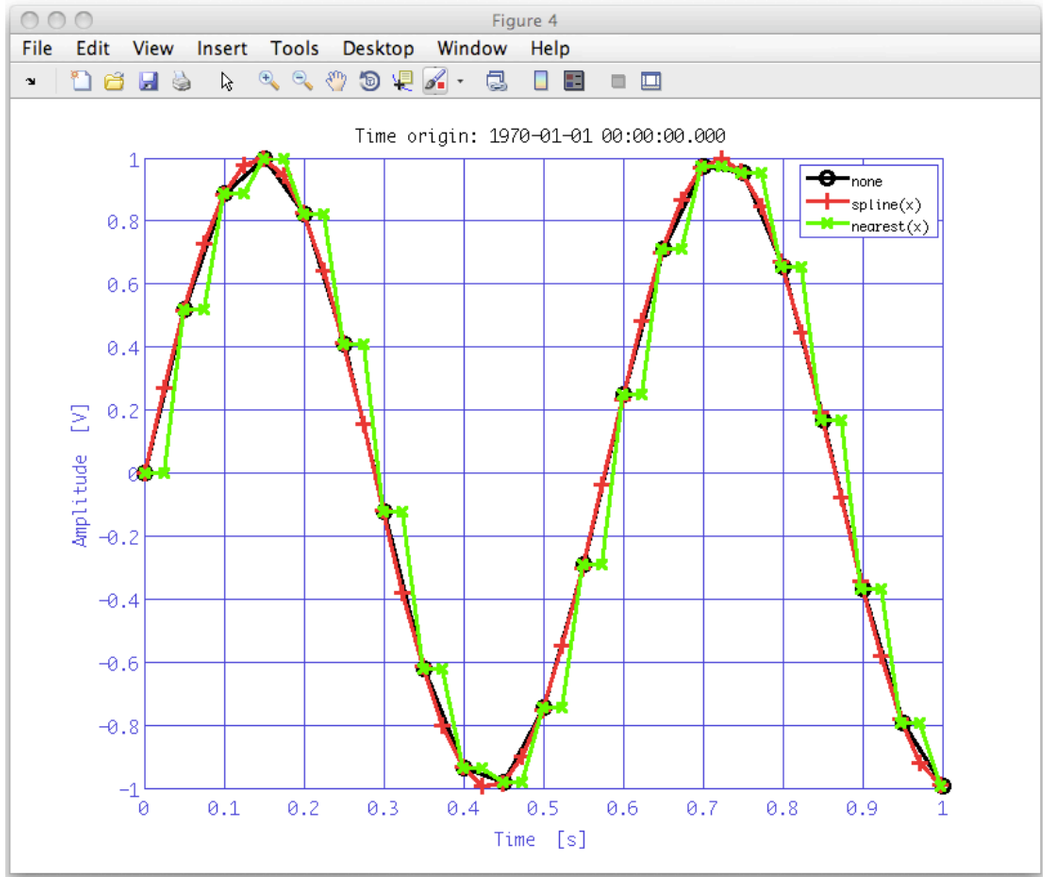
Interpolation



work through:
Topic 2- Interpolation

Interpolation

‘vertices’	new time grid
interpolation methods	
‘linear’	linear interpolation
‘spline’	spline interpolation
‘cubic’	cubic interpolation
‘nearest’	nearest neighbour

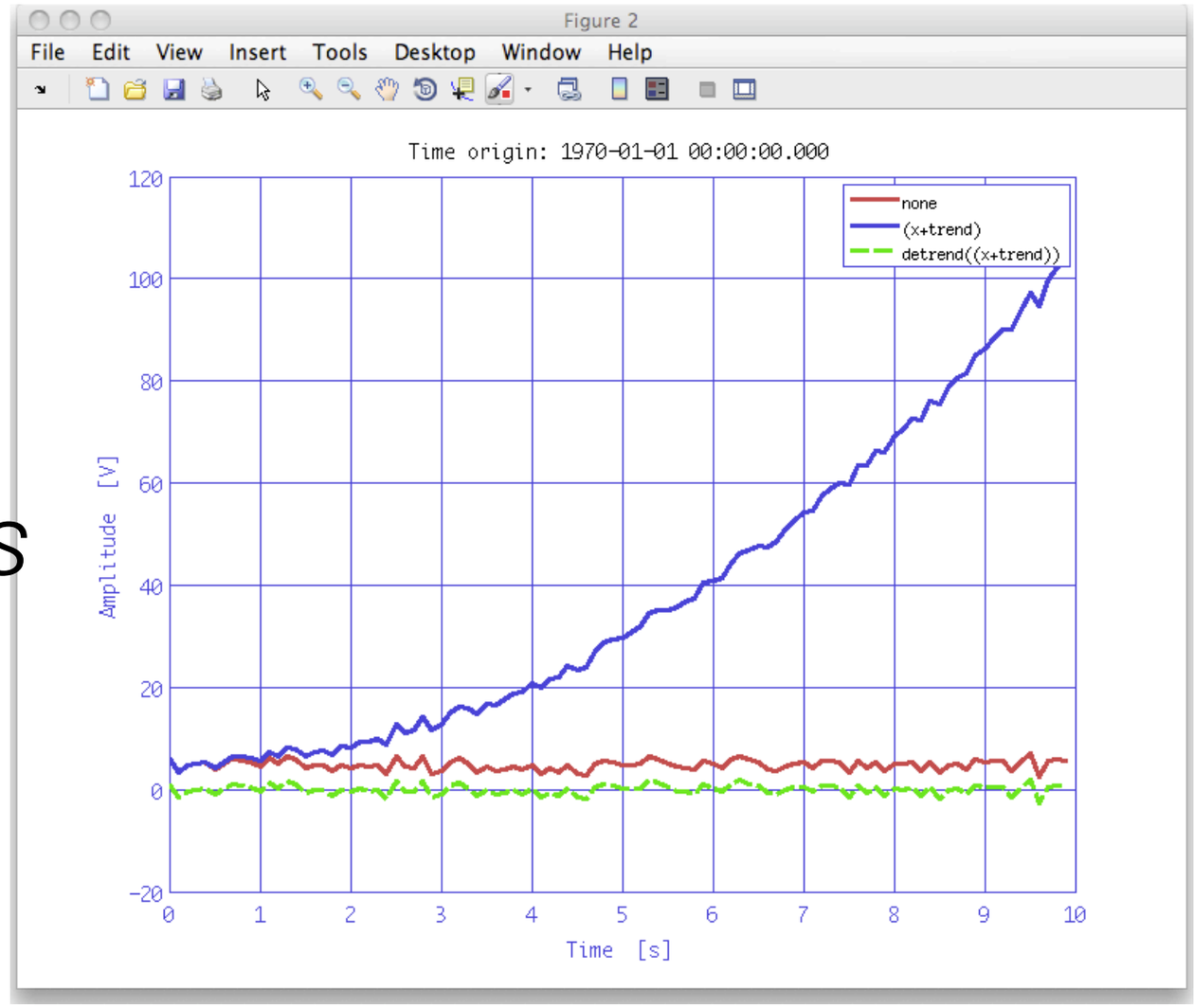


work through:
Topic 2- Interpolation

Detrending data

- Remove trends by
  - subtracting polynomial fit from data
- ao/detrend calls MATLABs polyfit

work through:
Topic 2- Removing trends



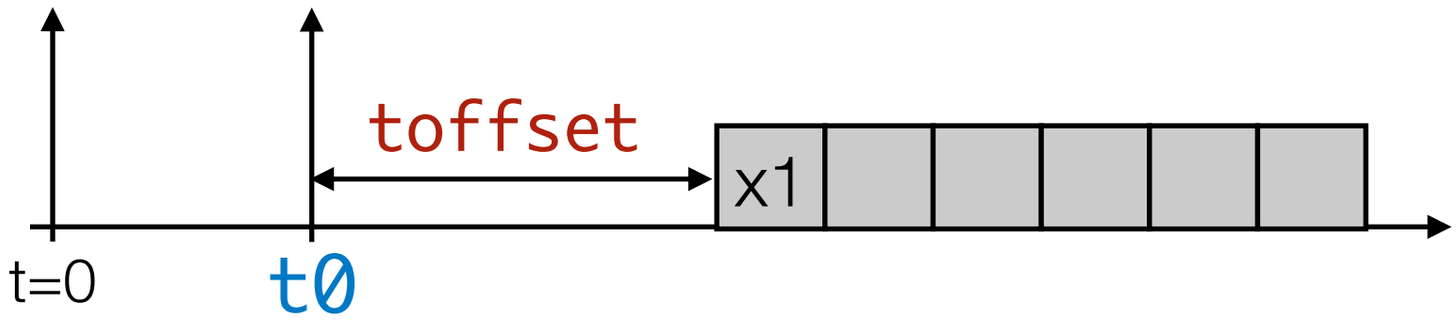
Whitening

- The LTDA Toolbox offers various ways to whiten your data
  - with a known filter
    - build filter and apply it to your data
  - with a known model of spectral content
    - use whiten1D
      - for single, uncorrelated data streams
    - whiten2D
      - for a pair of correlated data streams
  - without model (Exercise)
    - let whiten1D fit a model to the spectrum of your data

work through

Topic 2 whitening

Time-series in LTPDA v2.5



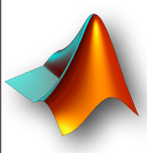
`setT0`	sets `t0` which means the data moves in time (`toffset` is unaffected)
`setReferenceTime`	sets `t0` and recalculates `toffset` to leave the data in place
`setToffset`	sets the `toffset` to the given value which means the data moves in time
`timeshift(dt)`	changes `toffset` by `dt`

Select & find/ split & join

- Chose the samples you want to analyse
  - find/select data samples by its properties
    - sample numbers - ‘select’
    - query for x and y values - ‘find’
  - split data by
    - intervals, times, frequencies, samples
- Group of functions helps you to
  - for find and select exactly the data you want split your data into pieces and eventually
  - join them back together

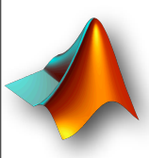
work through

Topic 2 - select and find, split and join



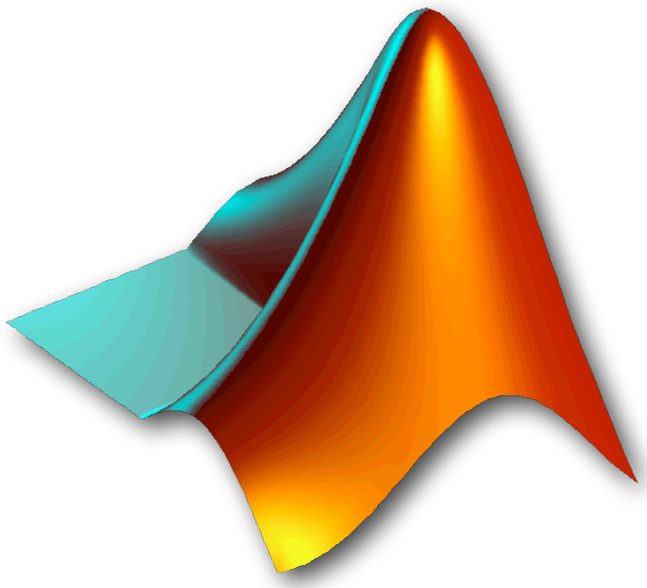
Pre-processing the IFO/Temp data

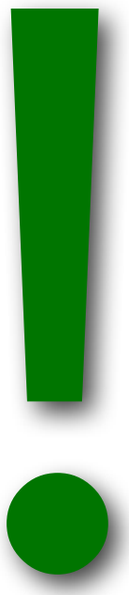
- There is a useful function which ‘cleans up’ the data
  - `consolidate`
- `consolidate` fixes our two data streams such that
  - they start at the same time
  - they have the same sampling rate
  - the are evenly sample on the same grid
- Work through
  - LTPDA Toolbox - LTPDA Training Session 1, Topic 2
    - IFO/Temp example



IFO-Temperature - topic 2

```
clear all;

%% Load calibrated IFO and temperature data
ifo  = ao('ifo_disp.mat');
temp = ao('temp_kelvin.mat');

%% Plot subplots
iplot(ifo, temp, plist('arrangement', 'subplots'))

%% Plot zoomed area
ppl = plist(...
  'arrangement', 'subplots', ...
  'linestyles', {'none', 'none'}, ...
  'markers', {'all', '+'}, ...
  'xranges', {'all', [200 210]}, ...
  'yranges', {[2e-7 3e-7], [200 350]});

iplot(ifo, temp, ppl)

%% Consolidate the two data series
[temp_fixed ifo_fixed] = consolidate(temp, ifo, plist('fs',1));

%% Plot fixed data
iplot(ifo, temp, ppl.pset('xranges', {'all', [0 20]}))
iplot(ifo_fixed, temp_fixed, ppl.pset('xranges', {'all', [0 20]}))

%% Save the data
save(temp_fixed,'temp_fixed.mat');
save(ifo_fixed,'ifo_fixed.mat');
```





Power Spectral Density Estimation (1)

Definition:

$$P_{xx}(f) = \frac{1}{f_s} \sum_{m=-\infty}^{+\infty} R_{xx}(m) \exp(-2\pi i \cdot f \cdot m / f_s)$$

Estimates the one-sided PSD:

$$\tilde{P}_{xx}(f) = \left\{ \begin{array}{ll} 0, & -\frac{f_s}{2} \leq f \leq 0 \\ 2P_{xx}(f), & 0 \leq f \leq \frac{f_s}{2} \end{array} \right\}$$

Power Spectral Density Estimation (2)

- The PSD at each frequency is estimated via the Welch method:
  - Given a discretized signal *x*[n] of length N, Data are divided into segments of length L and multiplied by a window
    - this also reduces the edge-effects (simulating a periodic sequence)
  - The PSD at each frequency f is estimated as:

$$\hat{P}_{xx}(f) = \frac{|X_L|^2}{f_s \cdot L \cdot U}$$

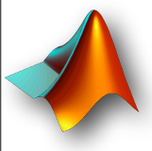
  - where

$$x_L[n] = x[n]w[n]$$

$$x_L(f) = \sum_{n=0}^{L-1} x_L[n] \exp\left(-2\pi i \cdot \frac{f \cdot n}{f_s}\right) \qquad U = \frac{1}{L}\sum_{n=0}^{L-1} \left|w(n)^2\right|$$

Power Spectral Density Estimation (3)

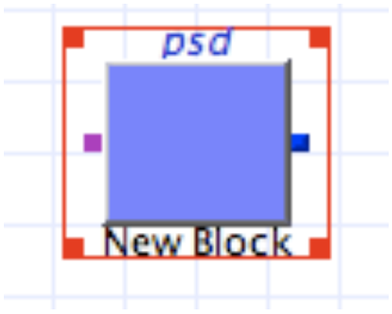
- Methods:
  - ao/psd: linear frequency scale
  - ao/lpsd: log-frequency scale
  - specwin: implements spectral windows



Power Spectral Density Estimation (4)

- a = [ao with time-series data]
- S = a.psd(plist('win',win,… 'nfft',nfft,'olap',olap,… 'order',order,'scale',scale))

Or add a block on a workbench:



Power Spectral Density Parameters

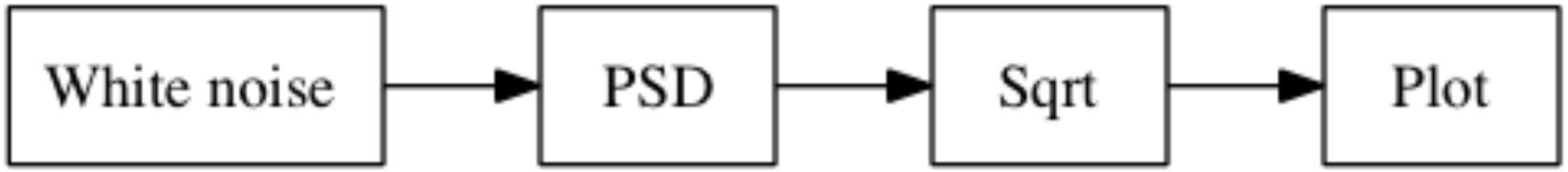
Name	Description	Values	Default
scale	the output quantity	‘PSD’ gives Power Spectral Density [m^2 Hz^-1] ‘ASD’ gives Amplitude Spectral Density [m Hz^-1/2] ‘PS’ gives Power Spectrum [m^2] ‘ASD’ gives Amplitude Spectrum [m]	‘PSD’
win	A spectral window to multiply the data by	‘BH92’ or ‘Rectangular’ or … (name or object)	Taken from user preferences
nfft	Window length	-1: one window, length = ao data set Or: length (number of points)	-1
order	Order of segment detrending (prior to windowing)	-1: no detrending 0: mean subtraction N: order N polynomial trend subtraction	0
olap	Percentage overlap between adjacent segments	-1: taken from window parameters 0: no overlap 100: total overlap	-1

Power Spectral Density Estimation (5)

- Features:
  - Multiple inputs:
    - S = psd(a1,a2,a3,plist())
  - Matrix inputs:
    - S = psd([a1 a2;a3 a4],plist())

PSD Exercise 1

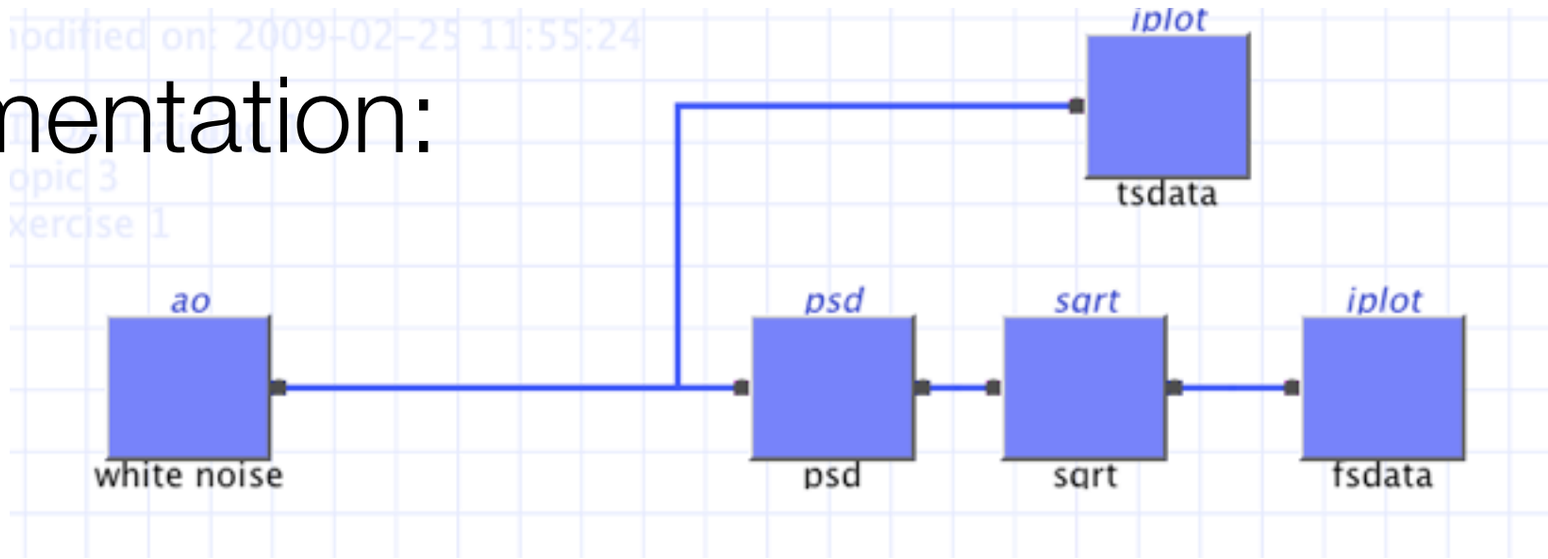
- Very simple idea:



Parameters for psd:
all default

PSD Exercise 1

Workbench implementation:

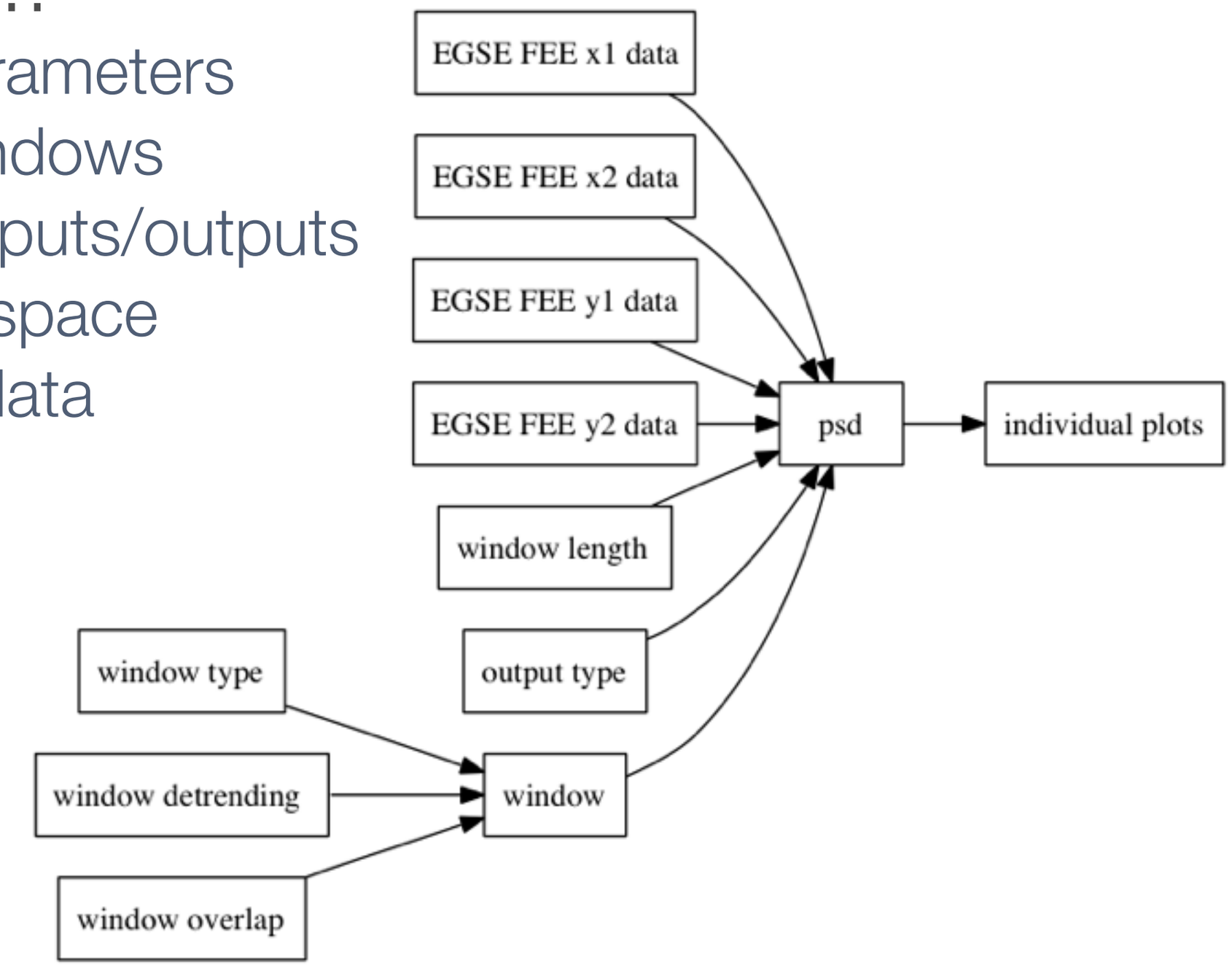


Matlab terminal implementation:

```
>> a1 = ao(plist('waveform','noise','type','normal','nsecs',
   1000,'sigma',1.0,'yunits','m'))
>> iplot(a1)
>> S1 = a1.psd(plist('win','BH92'))
>> P1 = sqrt(S1)
>> iplot(P1)
```

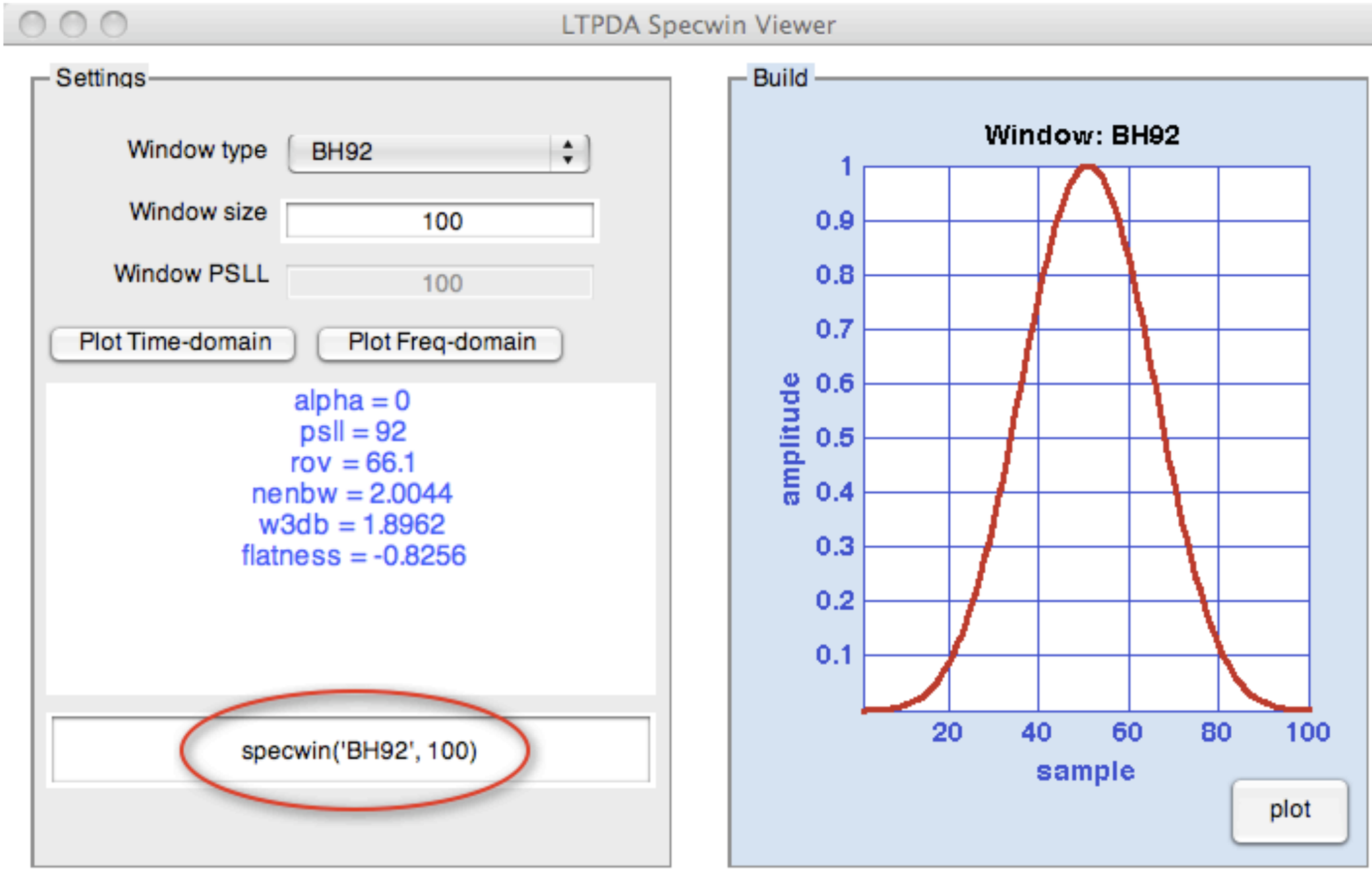
PSD Exercise 2

- More involved …
  - Playing with parameters
  - Playing with windows
  - Adding block inputs/outputs
  - Output to workspace
  - Saving output data



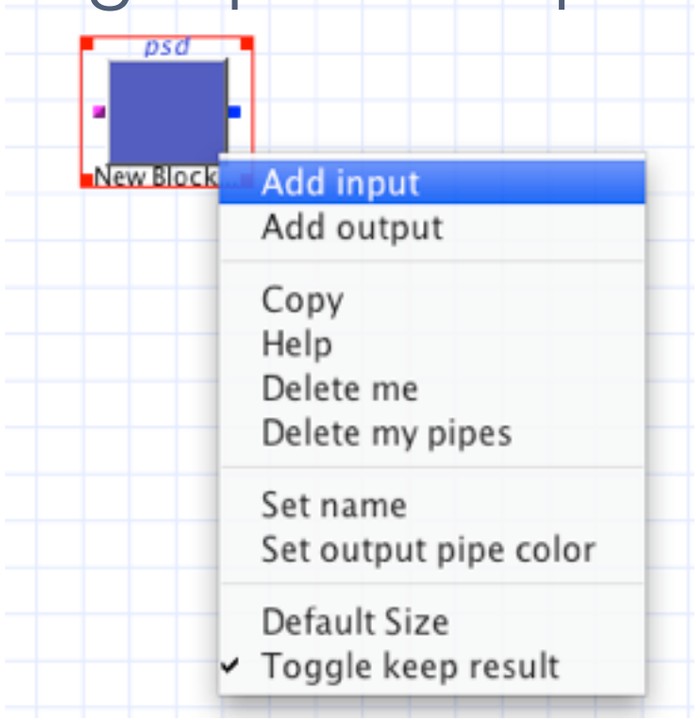
PSD Exercise 2

- Spectral windows



PSD Exercise 2

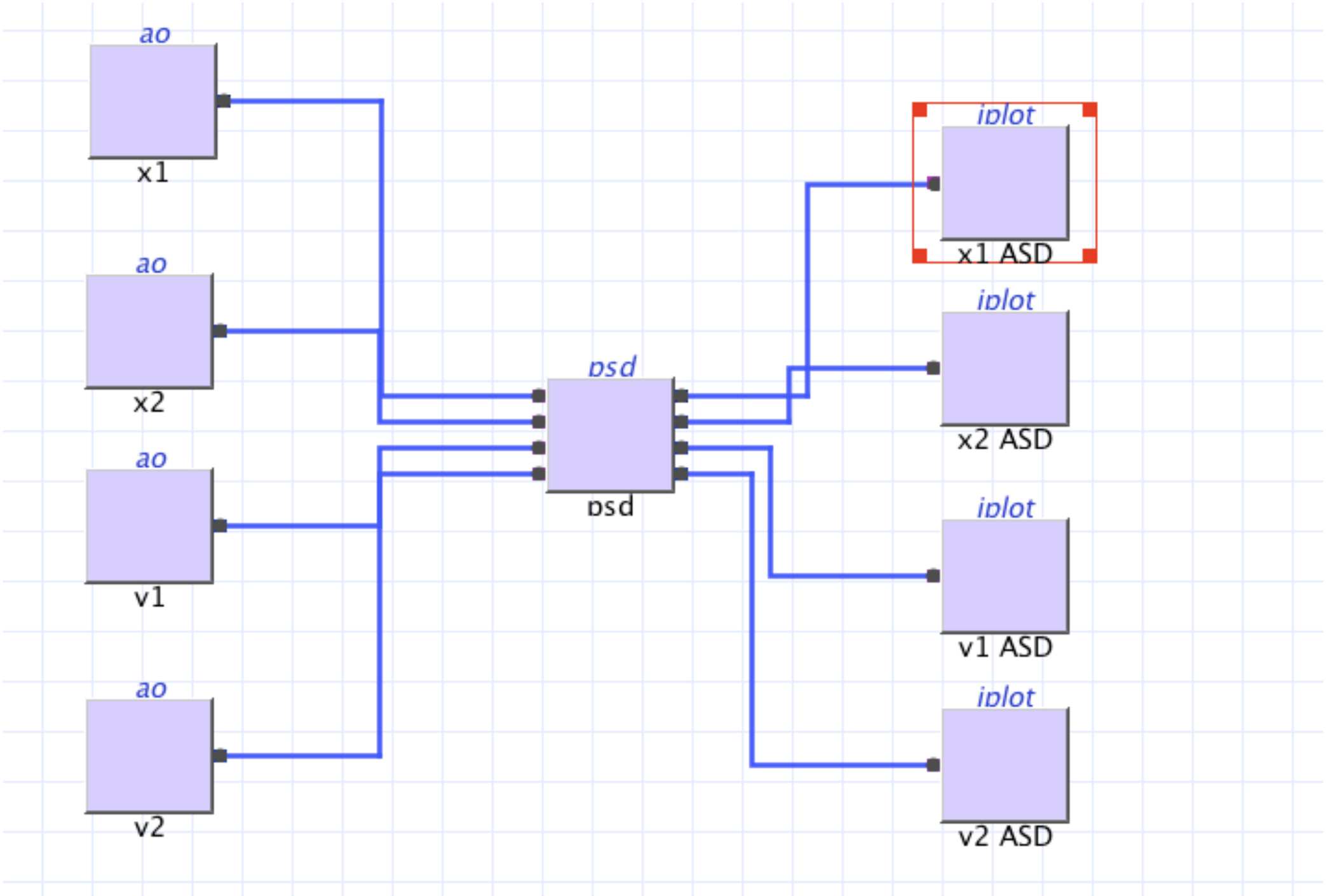
- Adding inputs/outputs to blocks



- Playing with parameters

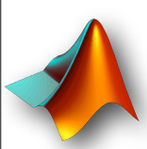
	Key	Value	Edit
☐	KDES	100.0	...
☐	JDES	1000.0	...
☐	LMIN	0.0	...
☐	WIN	BH92	...
☐	PSLL	200.0	...
☐	OLAP	-1.0	...
☐	ORDER	0.0	...
☐	TIMES	[]	...
☑	SCALE	PSD	...

PSD Exercise 2



Log-Scale Power Spectral Density Estimation

- Implementation of the algorithm described in
  - "Measurement 39 (2006) 120-129"
- The same as psd but:
  - Reduces individual point variance by adjusting the window length at each frequency
  - Frequency bins and number of averages are calculated automatically
  - Slower because of requires use of DFT rather than FFT
  - Energy content of the spectrum is preserved
  - Reduced resolution at high frequencies due to shorter window length
  - Lower uncertainty



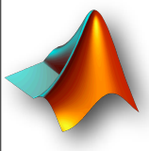
Log-Scale Power Spectral Density Parameters

- Parameters:

Name	Description	Values	Default
Kdes	Desired number of averages	An integer number	100
Jdes	Desired number of spectral frequencies to calculate	An integer number	1000
Lmin	Minimum segment length	An integer number	0

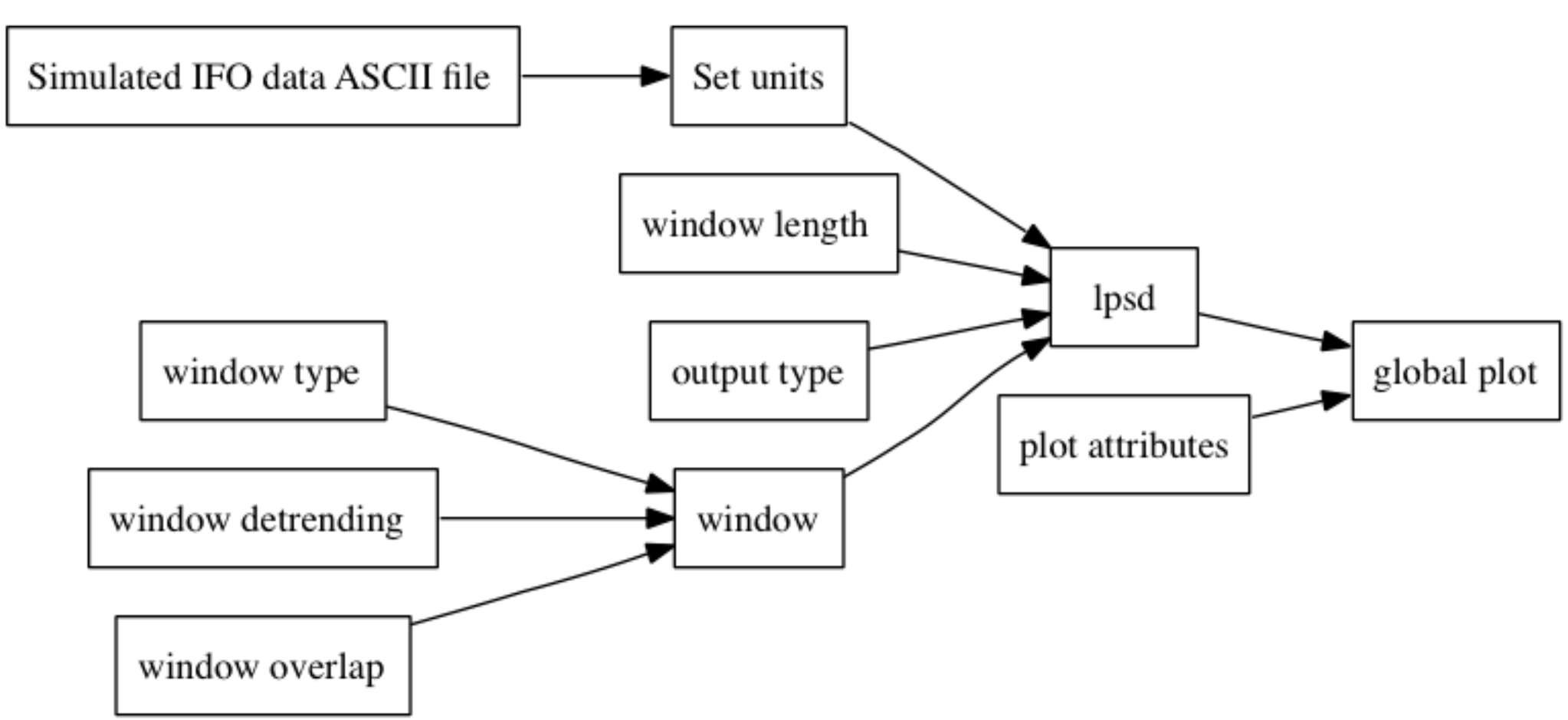
Log-scale Power Spectral Density Estimation

- Features:
- Multiple inputs:
  - S = lpsd(a1,a2,a3,plist())
- Matrix inputs:
  - S = lpsd([a1 a2;a3 a4],plist())



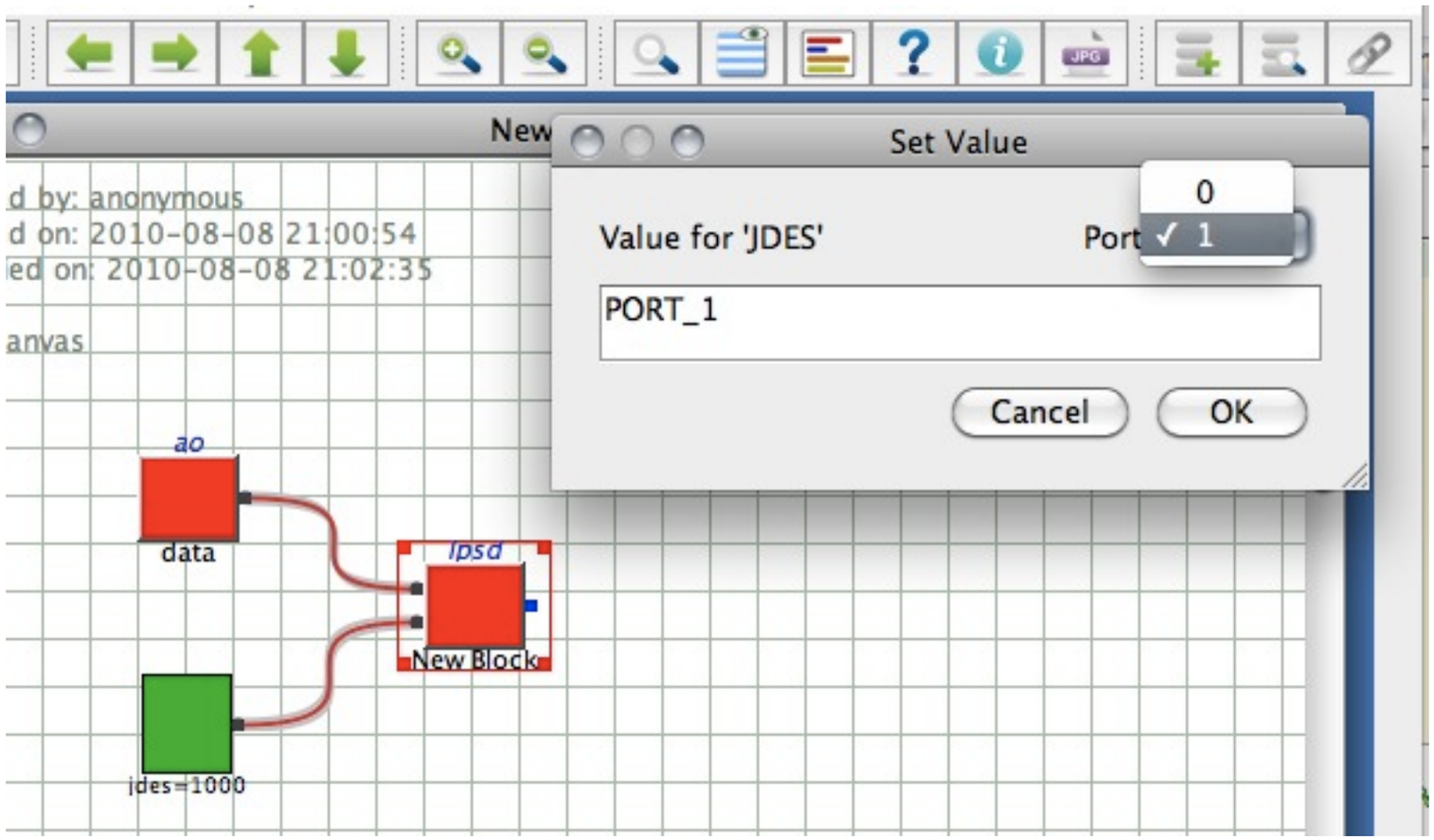
PSD Exercise 3

- Using lpsd
  - Log-scale psd calculation to reduce variance
  - Using MDC1 IFO data
  - Setting units
  - Setting plot features

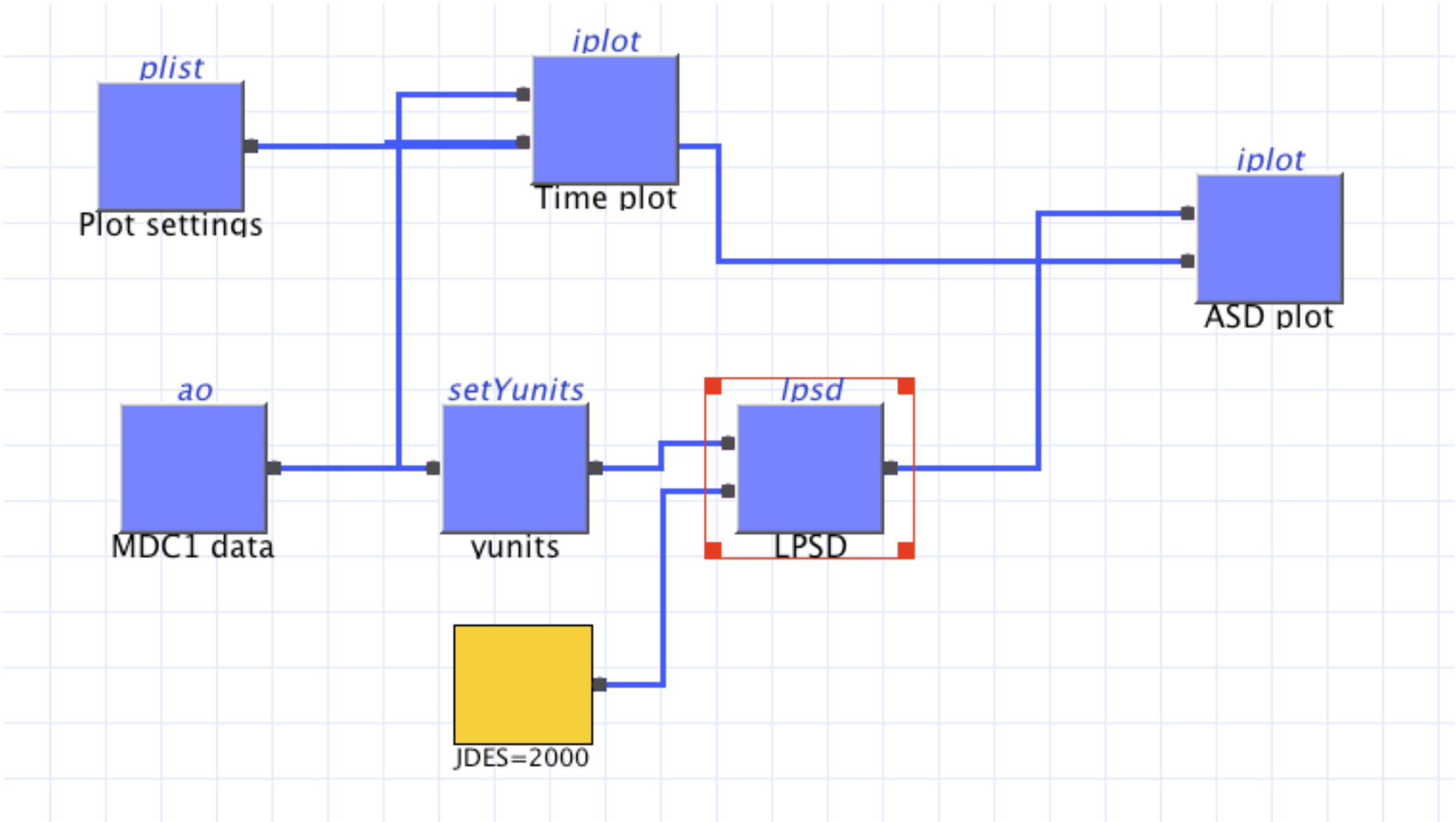


PSD Exercise 3

- Passing values as parameter values



PSD Exercise 3



Cross-Power Spectral Density Estimation

Definition:

$$C_{xy}(f) = \frac{1}{f_s} \sum_{m=-\infty}^{+\infty} R_{xy}(m) \exp(-2\pi i \cdot f \cdot m / f_s)$$

Estimates the *one-sided* CPSD:

$$\tilde{C}_{xy}(f) = \left\{ \begin{array}{ll} 0, & -\frac{f_s}{2} \le f \le 0 \\ 2P_{xy}(f), & 0 \le f \le \frac{f_s}{2} \end{array} \right\}$$

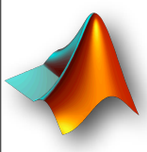
Cross- Power Spectral Density Estimation (2)

- Use Welch method as in PSD
- The CPSD at each frequency f is estimated as:

$$\hat{C}_{xy}(f) = \frac{X_L Y_L^*}{f_s \cdot L \cdot U}$$

- where:

$$x_L(f) = \sum_{n=0}^{L-1} x_L[n] \exp\left(-2\pi i \cdot \frac{f \cdot n}{f_s}\right) \qquad U = \frac{1}{L}\sum_{n=0}^{L-1} \left| w(n)^2 \right|$$



Cross- Power Spectral Density Estimation (3)

- Methods:
  - ao/cpsd: linear frequency scale
  - ao/lcpsd: log-frequency scale

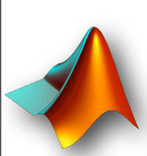
Similarly, we can evaluate coherence:

$$Coh_{xy}(f) = \frac{\left|C_{xy}(f)\right|^2}{P_{xx}(f)P_{yy}(f)}$$

Methods:
ao/cohere: linear frequency scale
ao/lcohere: log-frequency scale

Cross- Power Spectral Density Estimation (4)

```
pl = plist(...
   'win',win,...
   'nfft',nfft,...
   'olap',olap,...
   'order',order,...
   'scale',scale);

Cxy = cpsd(x, y, pl)
```



Cross- Power Spectral Density Parameters

Name	Description	Values	Default
win	A spectral window to multiply the data by	'BH92' or 'Rectangular' or … name or object	Taken from user preferences
nfft	Length of the window	-1: one window, length = ao data set length Or: length (number of points)	-1
order	Order of segment detrending (prior to windowing)	-1: no detrending 0: mean subtraction N: order N polynomial trend subtraction	0
olap	Percentage overlap between adjacent segments	-1: taken from window parameters 0: no overlap 100: total overlap	-1

Transfer Function Estimation

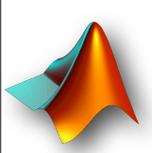
- Methods:
  - ao/tfe: linear frequency scale
  - ao/ltfe: log-frequency scale
- Definition:

$$T_{xy}(f) = \frac{C_{xy}(f)}{P_{yy}(f)}$$

- Use Welch method again

Transfer Function Estimation (2)

```
pl = plist(...
    'win',win,...
    'nfft',nfft,...
    'olap',olap,...
    'order',order,...
    'scale',scale);

Txy = tfe(x, y, pl)
```



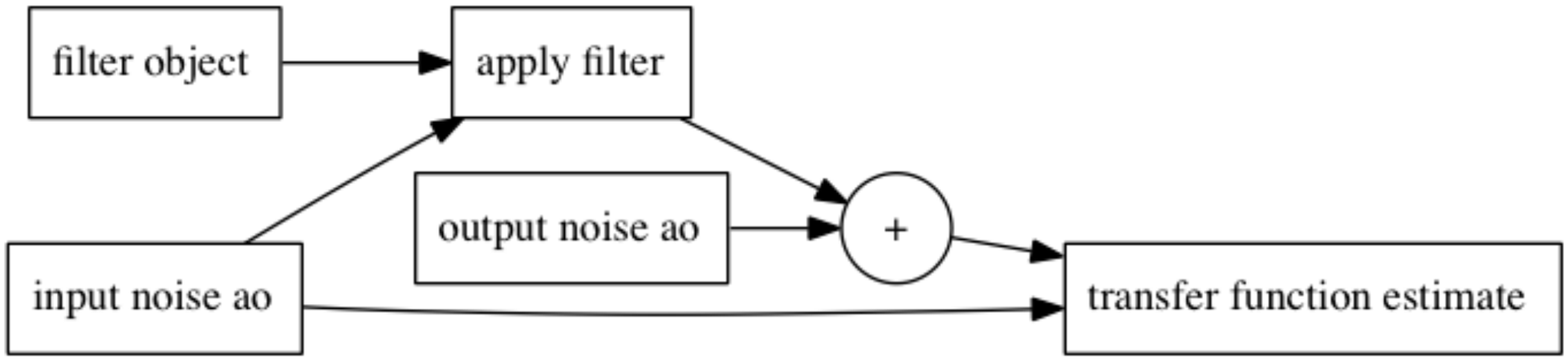
Transfer Function Estimation Parameters

Name	Description	Values	Default
win	A spectral window to multiply the data by	'BH92' or 'Rectangular' or … name or object	Taken from user preferences
nfft	Length of the window	-1: one window, length = ao data set length Or: length (number of points)	-1
order	Order of segment detrending (prior to windowing)	-1: no detrending 0: mean subtraction N: order N polynomial trend subtraction	0
olap	Percentage overlap between adjacent segments	-1: taken from window parameters 0: no overlap 100: total overlap	-1

And similarly for `ltfe` …

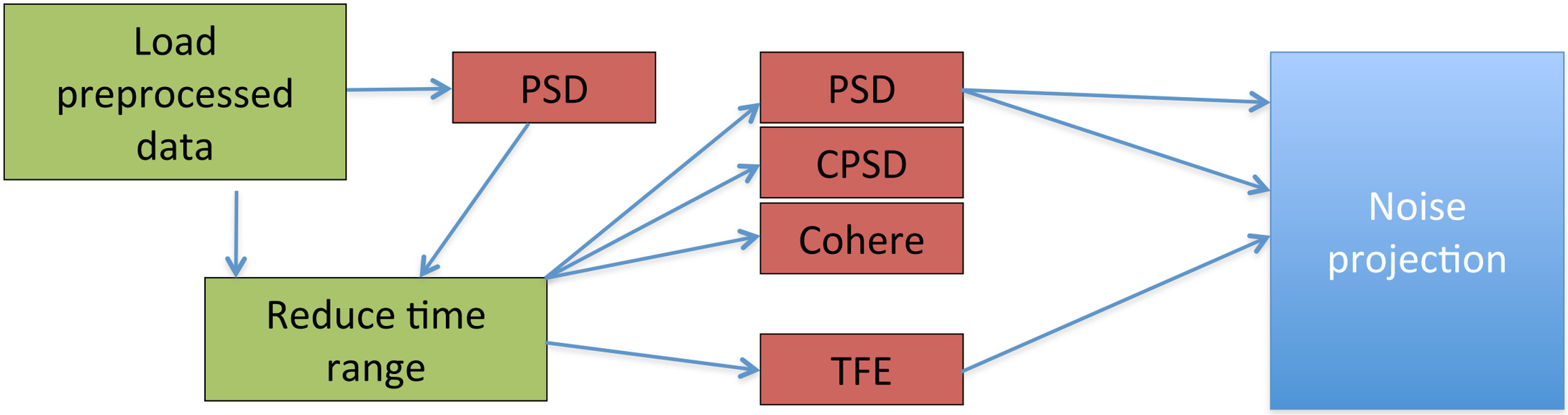
TFE Exercise 1

- Using tfe
  - Simulated data input: white noise
  - Band-pass filter object
  - Filtering the input noise
  - Adding output white noise
  - Estimate the transfer function



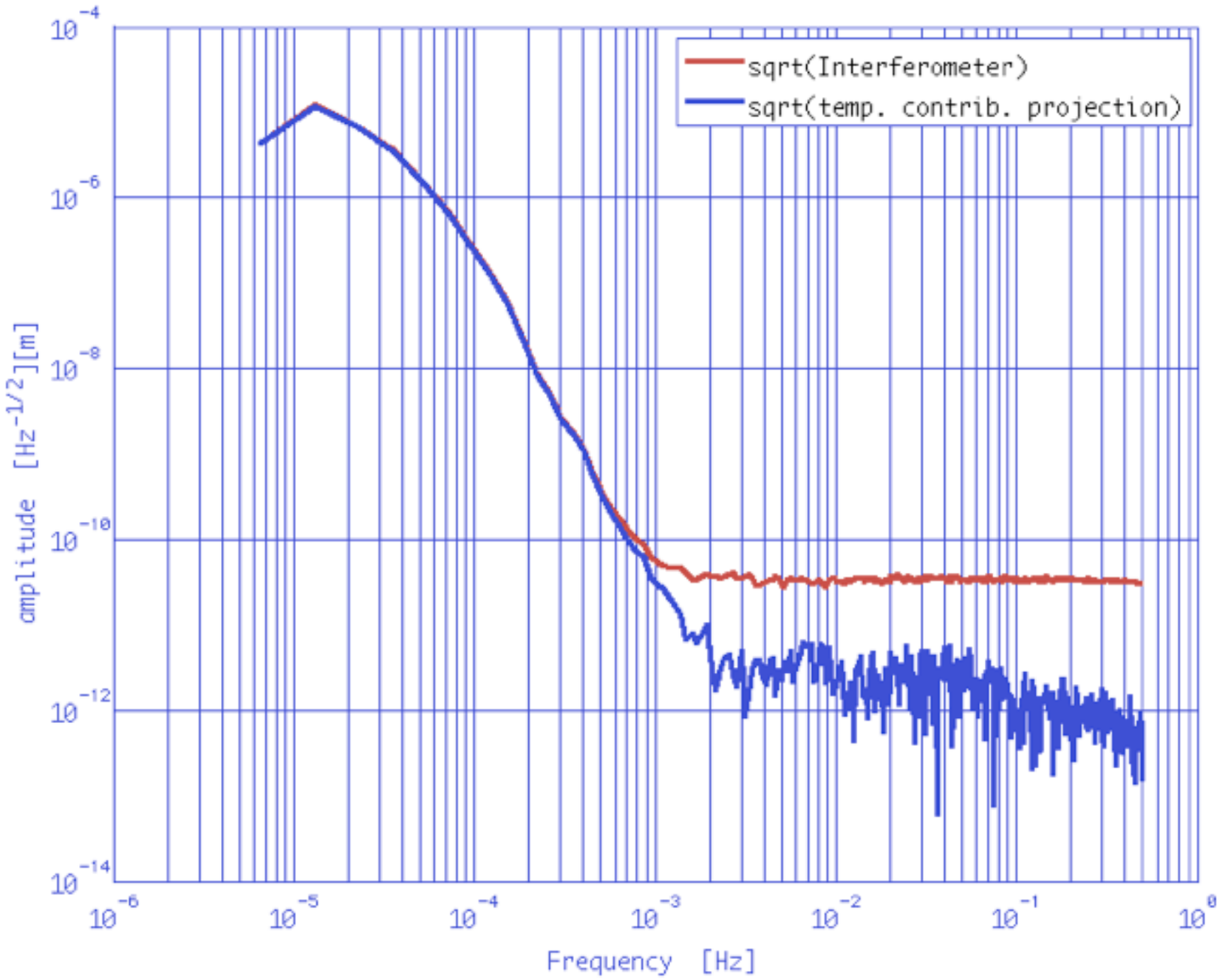
IFO/Temperature Example

- Estimating the empirical transfer function: temperature -> position
  - Load preprocessed data
  - Evaluate PSD of T and x
  - Reduce the time range
  - Evaluate CPSD and cross-coherence of T and x
  - Estimate the transfer function of T into x
  - Perform the noise projection



IFO/Temperature Example

- We are aiming to obtain:

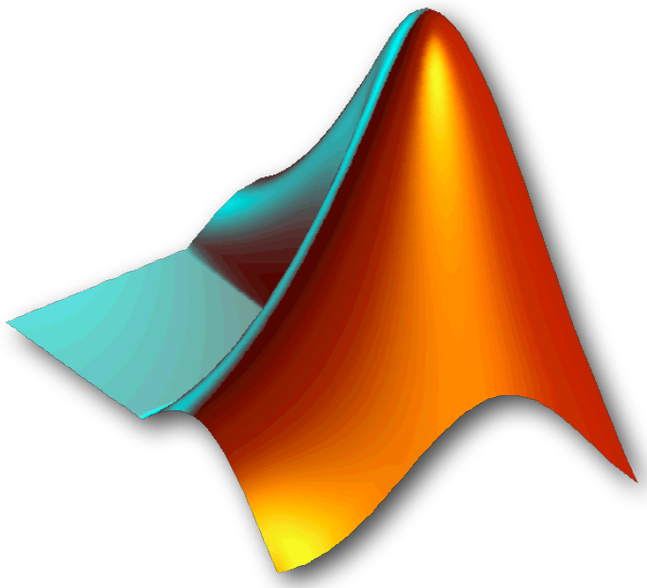


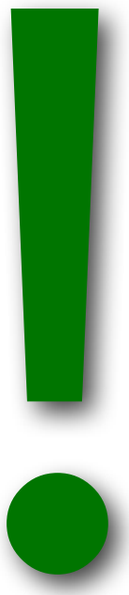
IFO/Temp - topic 3, part 1

```
clear all;

%% Load consolidated data
x = ao('ifo_fixed.mat');
T = ao('temp_fixed.mat');

%% Estimate PSD
x_psd = lpsd(x)
x_psd.setName('Interferometer');
T_psd = lpsd(T)
T_psd.setName('Temperature');

% Plot estimated PSD
pl_plot = plist('Arrangement', 'subplots', 'LineStyles', {'-','-'},'Linecolors', {'b', 'r'});
iplot(sqrt(x_psd), sqrt(T_psd), pl_plot);

%% Skip some IFO glitch from the consolidation
pl_split = plist(...
  'start_time', x.t0 + 40800, ...
  'end_time', x.t0 + 193500);

x_red = split(x, pl_split);
T_red = split(T, pl_split);

%% PSD
x_red_psd = lpsd(x_red);
x_red_psd.setName('Interferometer');
T_red_psd = lpsd(T_red)
T_red_psd.setName('Temperature');

% Plot estimated PSD
pl_plot = plist('Arrangement', 'stacked', 'LineStyles', {'-','-'},'Linecolors', {'b', 'r'});
iplot(sqrt(x_psd), sqrt(x_red_psd), pl_plot);
iplot(sqrt(T_psd), sqrt(T_red_psd), pl_plot);

%% CPSD estimate
CTx = lcpsd(T_red, x_red);
CxT = lcpsd(x_red, T_red);
% Plot estimated CPSD
iplot(CTx);
iplot(CxT);
```

IFO/Temp - topic 3, part 2

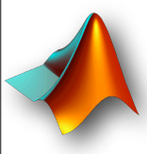
```
%% Coherence estimate
coh = lcohere(T_red, x_red);
% Plot estimated cross-coherence
iplot(coh, plist('YScales', 'lin'))

%% transfer function estimate
tf = ltfe(T_red, x_red)

% Plot estimated TF
iplot(tf, plist('autoerrors', true));

%% Noise projection in frequency domain

proj = T_red_psd.*(abs(tf)).^2;
proj.simplifyYunits;
proj.setName('temp. contrib. projection')

%% Plotting the noise projection in frequency domain
iplot(x_red_psd, proj);

%% Save

pl_save_x_PSD = plist('filename', 'ifo_psd.mat');
pl_save_T_PSD = plist('filename', 'T_psd.mat');

pl_save_xT_CPSD = plist('filename', 'ifo_T_cpsd.mat');
pl_save_xT_cohere = plist('filename', 'ifo_T_cohere.mat');

pl_save_xT_TFE = plist('filename', 'T_ifo_tf.mat');

x_red_psd.save(pl_save_x_PSD);
T_red_psd.save(pl_save_T_PSD);
CxT.save(pl_save_xT_CPSD);
coh.save(pl_save_xT_cohere);
tf.save(pl_save_xT_TFE);
```





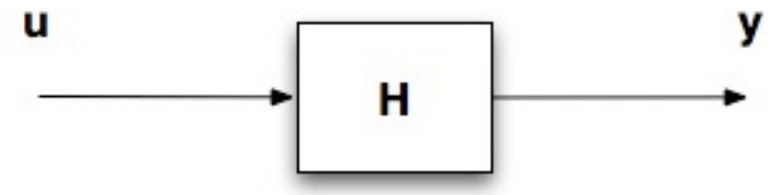
Topic 4: Transfer function models and digital filters

- Transfer function models in *s* domain
  - Pole zero representation
  - Rational representation
  - Partial fraction representation
- Transformation between representations
- Modeling a system
- Filtering data
  - discretizing a model
  - setting filter properties
- IFO/Temperature example



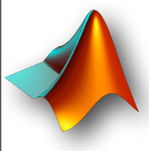
Overview

- The general scheme: input, output and a transfer function



- Aim of this topic:
  - How to model the transfer function *H* in continuous domain, *H = H(s)*
  - How to discretize our model *H(s)* -> *H(z)*
  - How to filter data with *H(z)*
  - How to define *H(z)* from filter properties

Tools used here



Tools used here

1. Continuous domain

Tools used here

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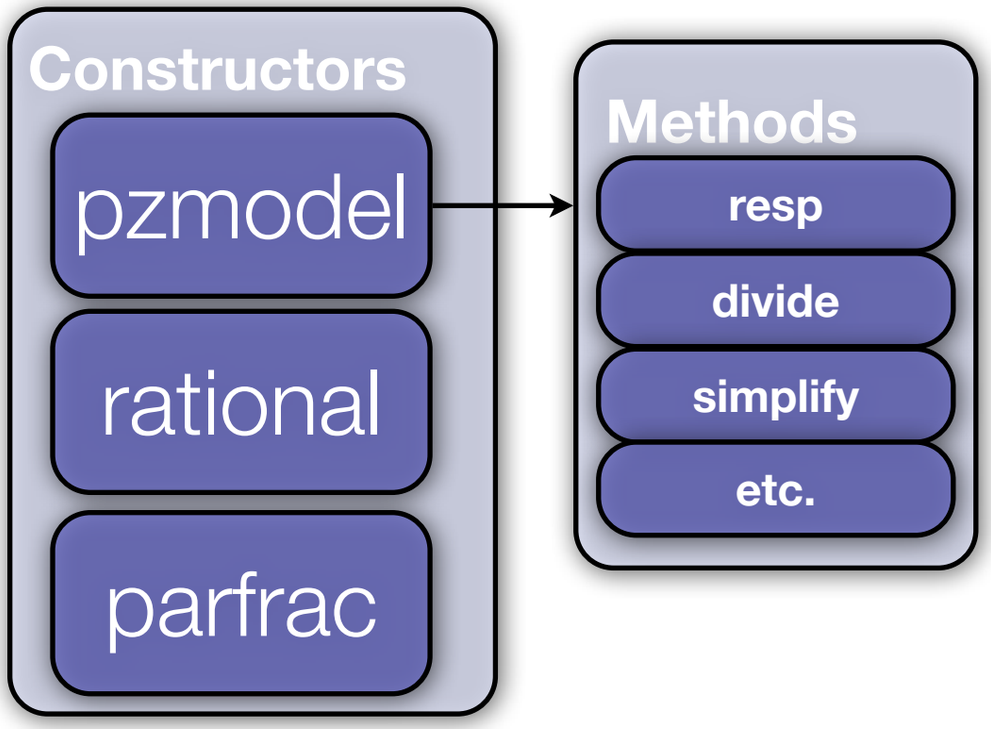
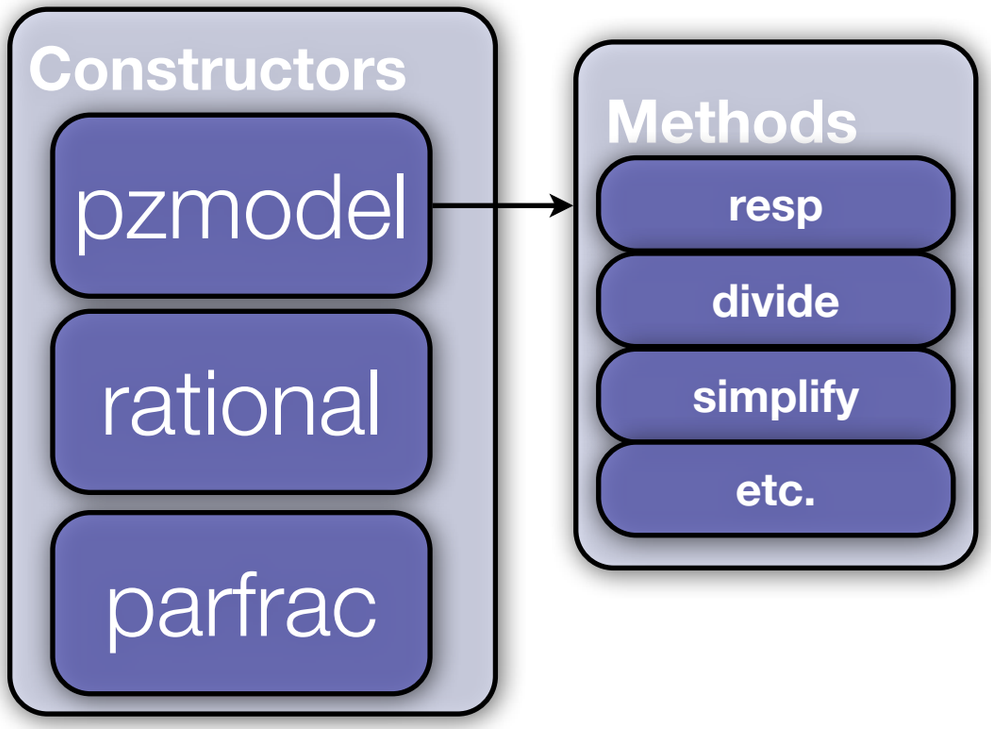


Tools used here

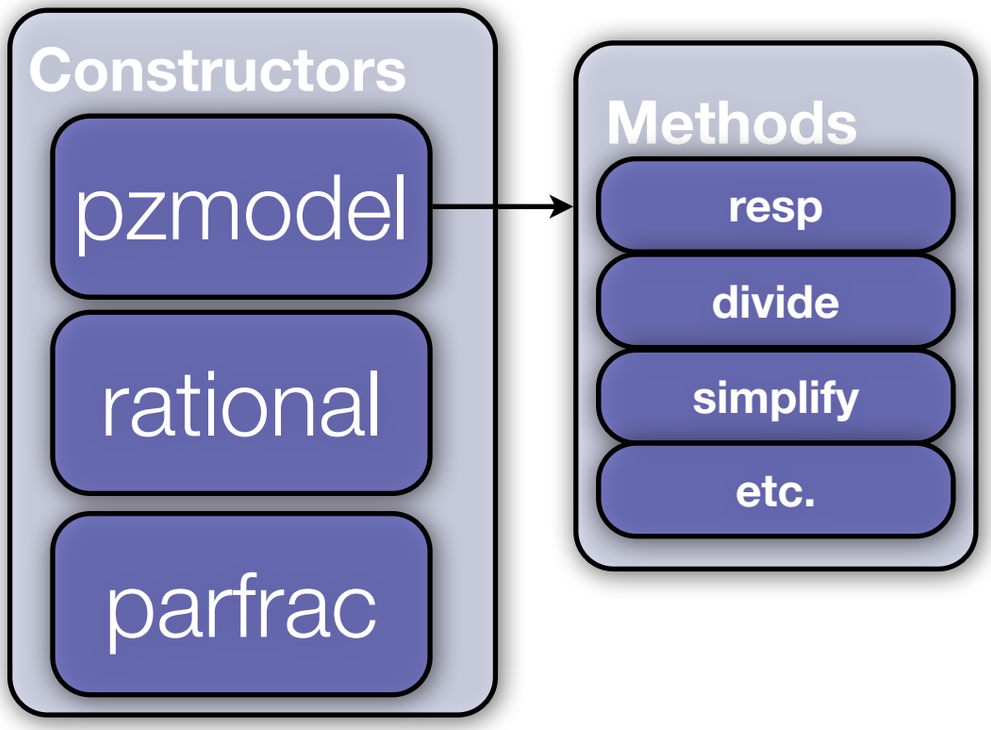
1. Continuous domain



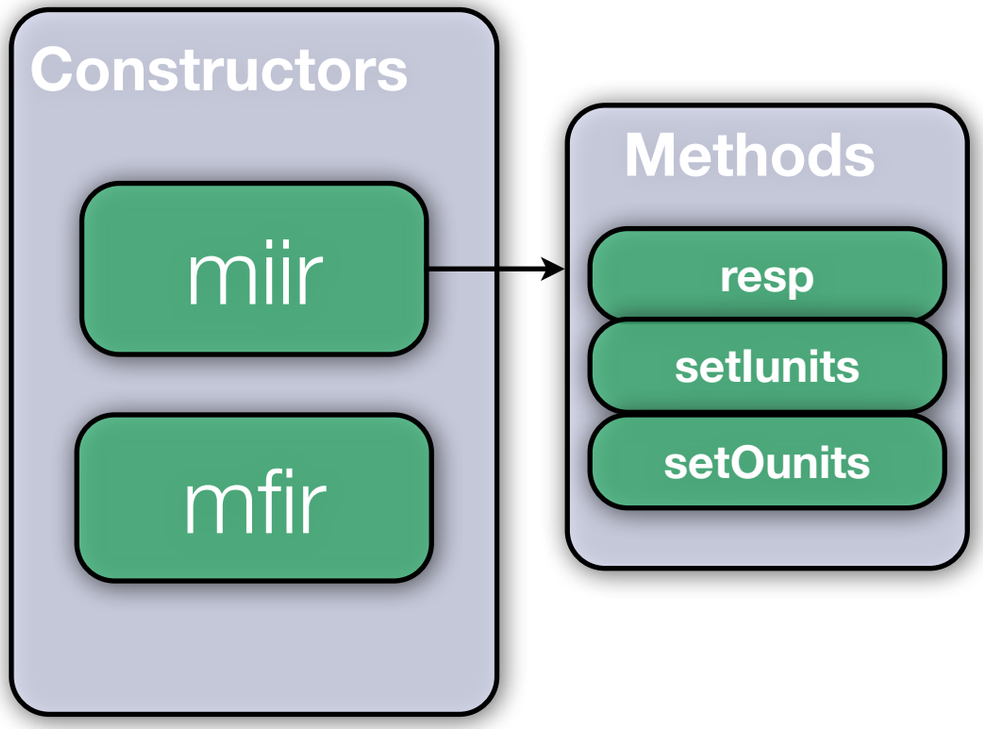
2. Discrete domain

Tools used here

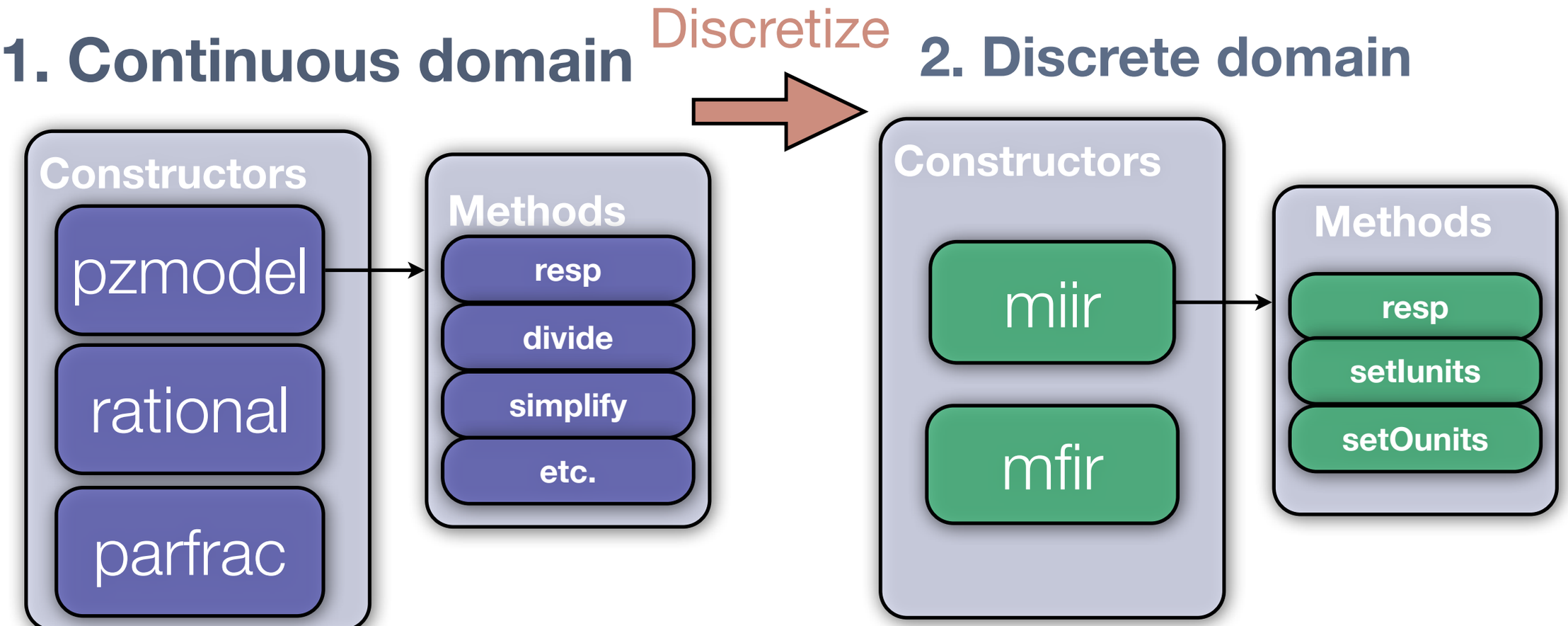
1. Continuous domain



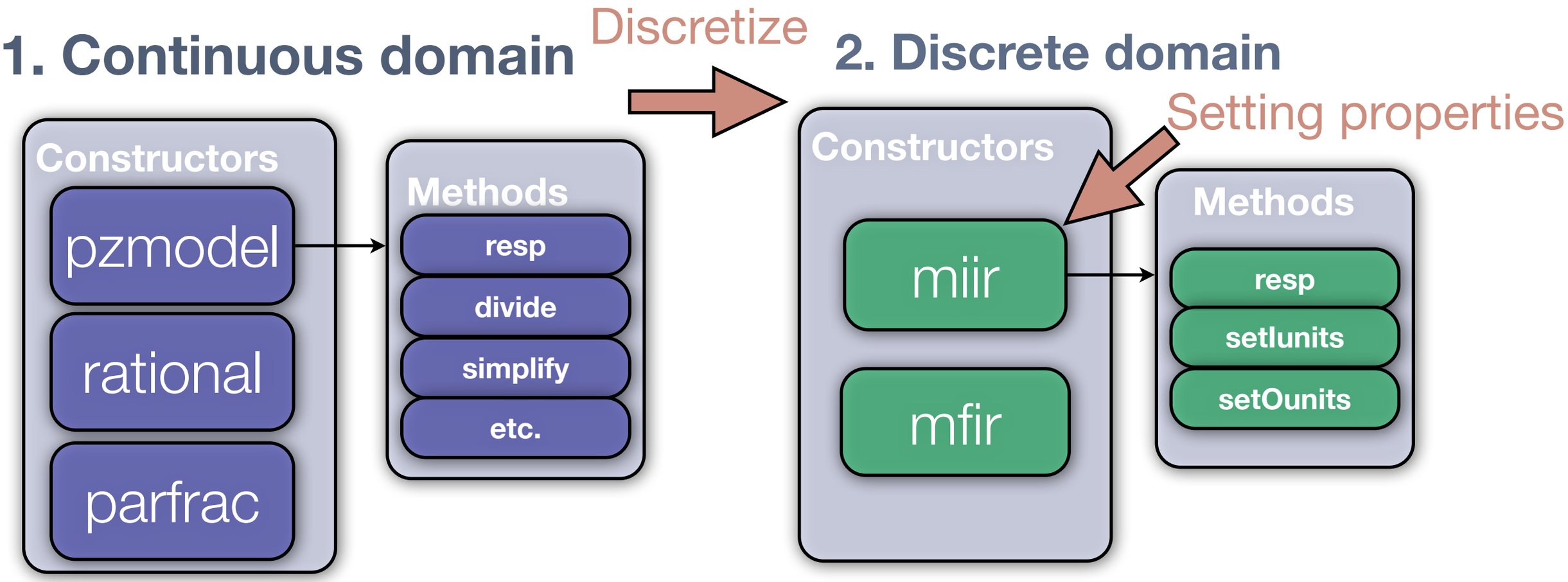
2. Discrete domain



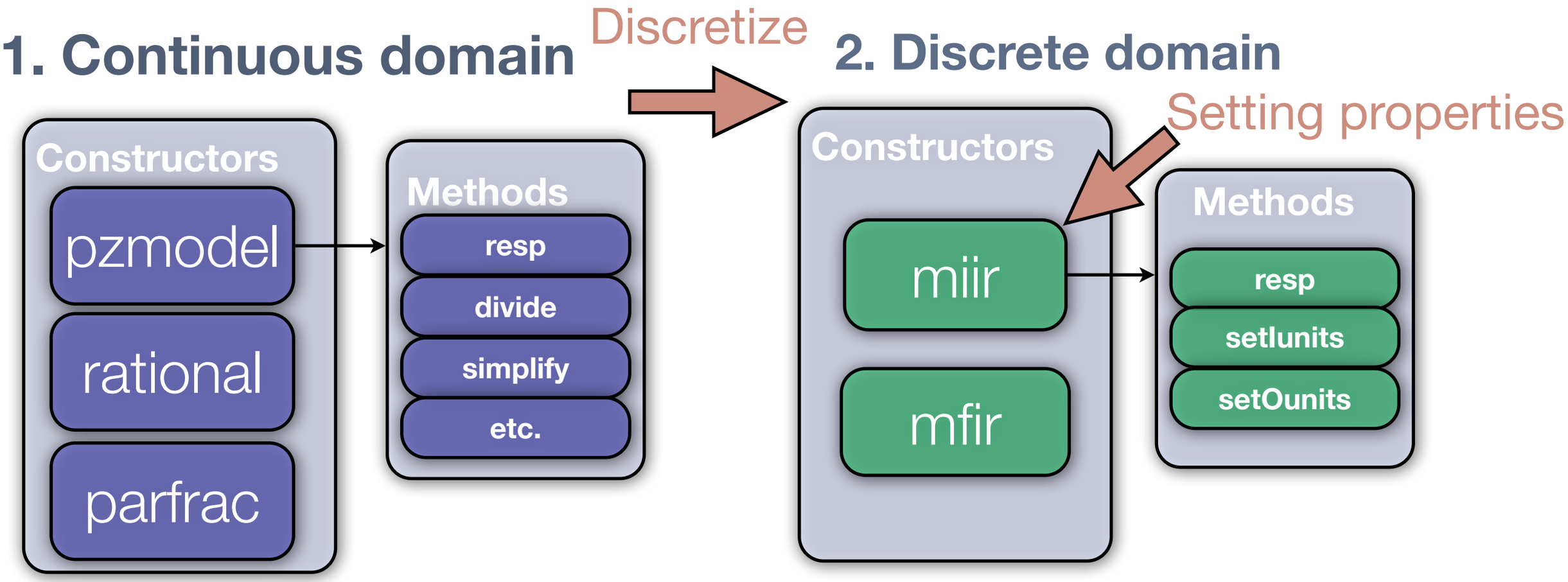
Tools used here



Tools used here

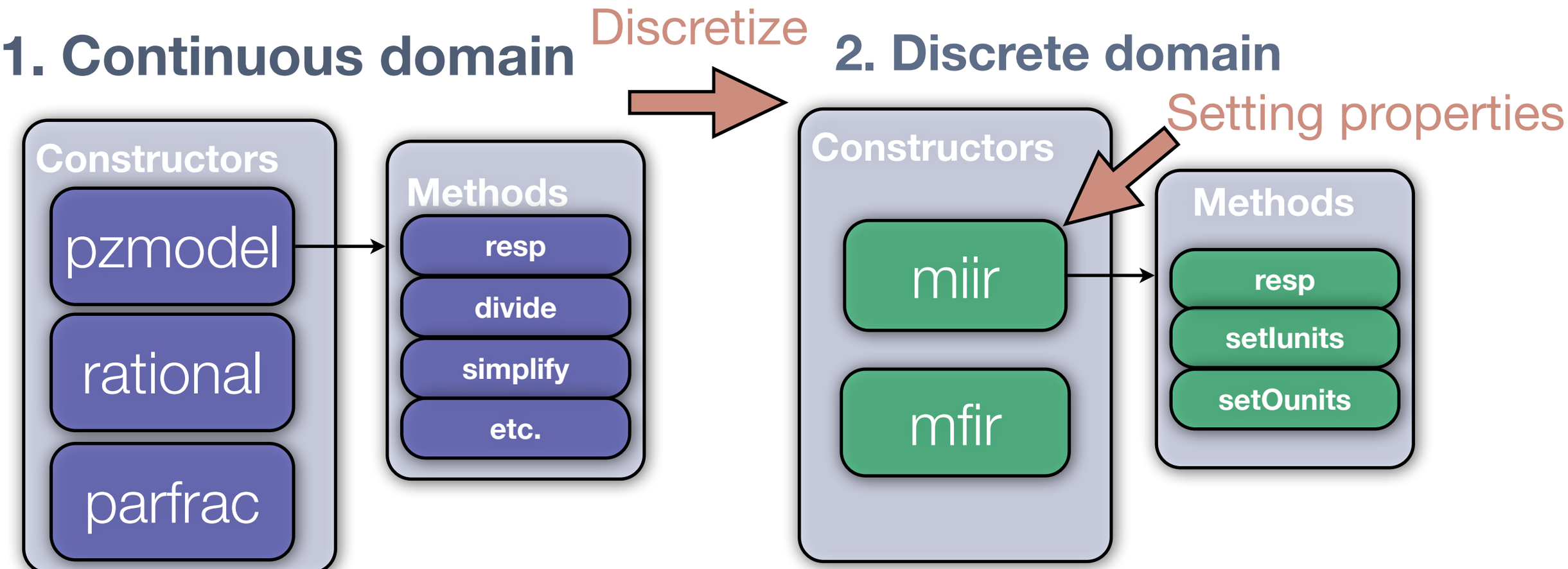


Tools used here



3. Filter data

Tools used here



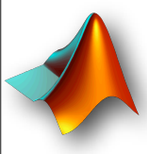
3. Filter data

Pole/zero models

- A pole zero model is defined by:
  - Gain, poles, zeros, delay

$$H(s) = G\frac{(s-z_1)(s-z_2)\dots(s-z_n)}{(s-p_1)(s-p_2)\dots(s-p_m)}e^{-i\omega\tau}$$

- LTPDA constructor: PZMODEL
  - PZMODELs can be multiplied and divided
  - Delay is added or subtracted in such a case



About poles (and zeros) notation

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- Simple pole: f = 1 Hz

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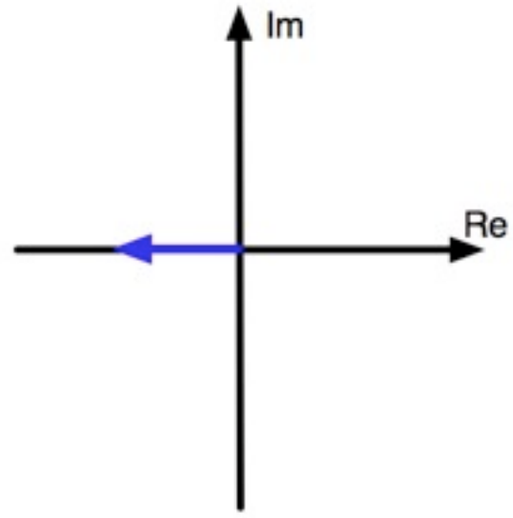
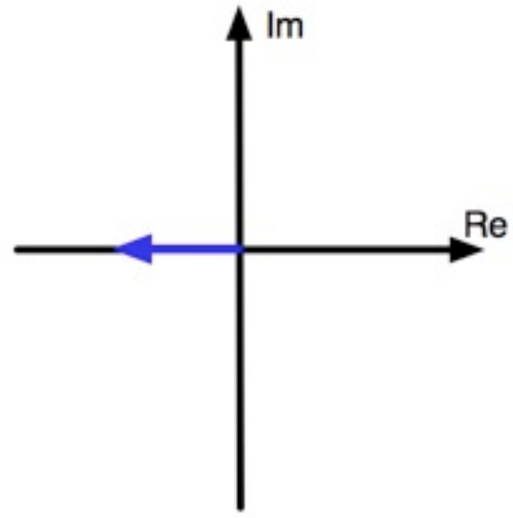


About poles (and zeros) notation

- Simple pole: f = 1 Hz
- Pole pairs: (f = 1 Hz, Q)



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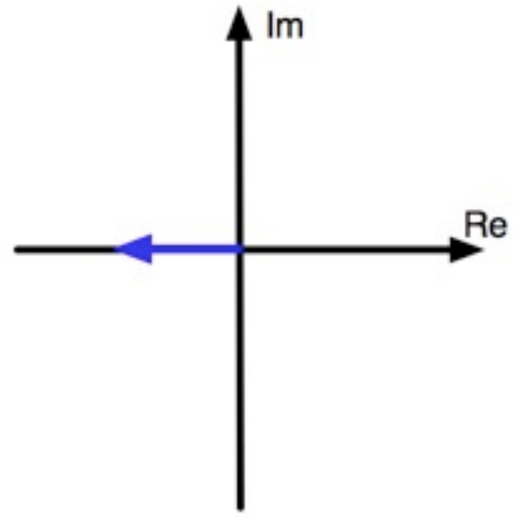

- Pole pairs: (f = 1 Hz, Q)

  Q > 0.5
  (underdamped)

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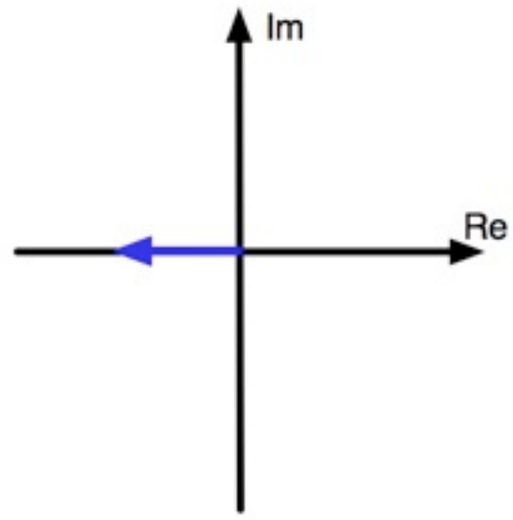

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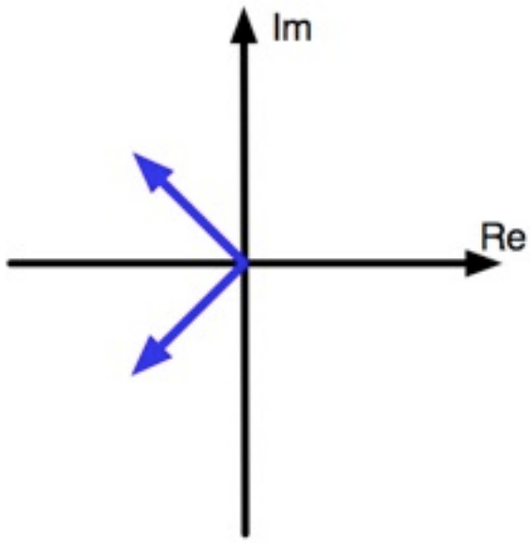

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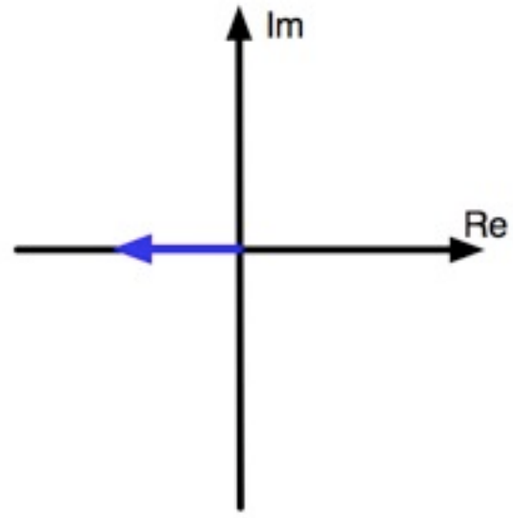

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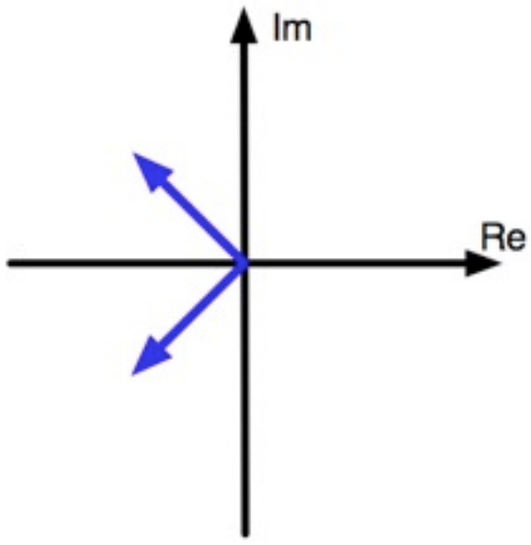

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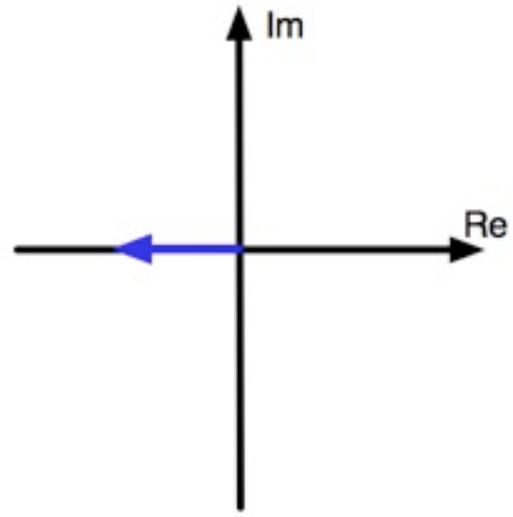

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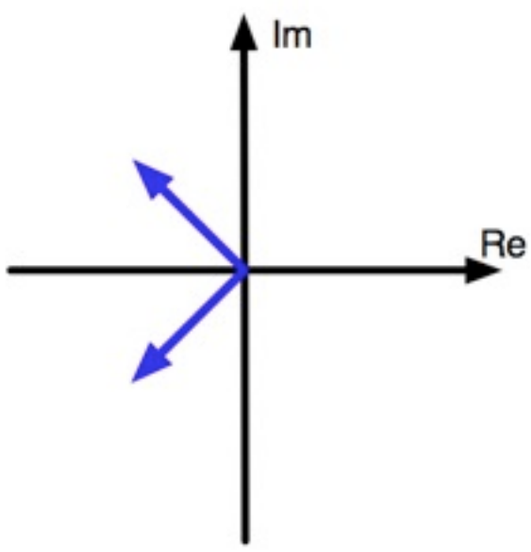

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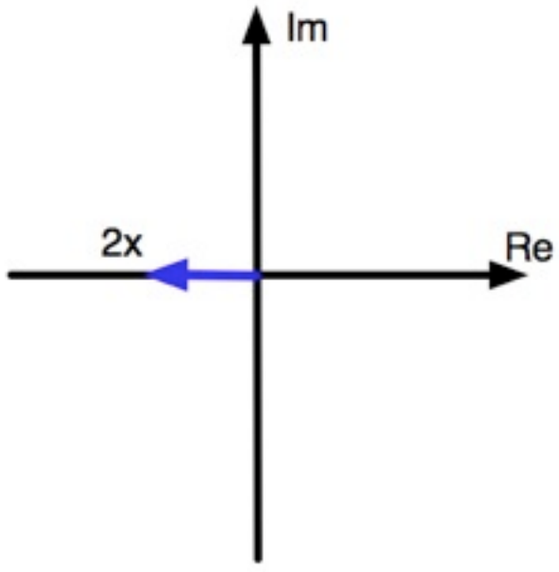

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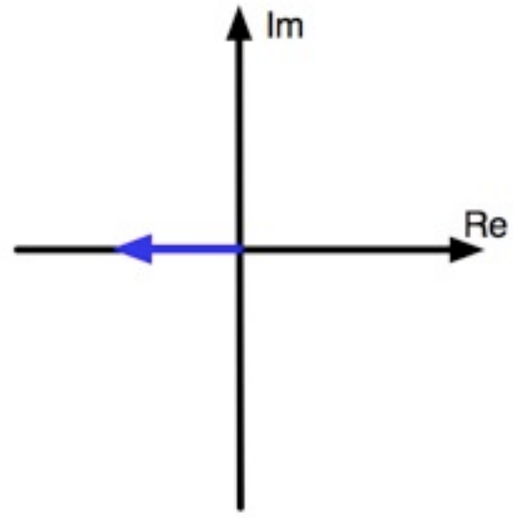

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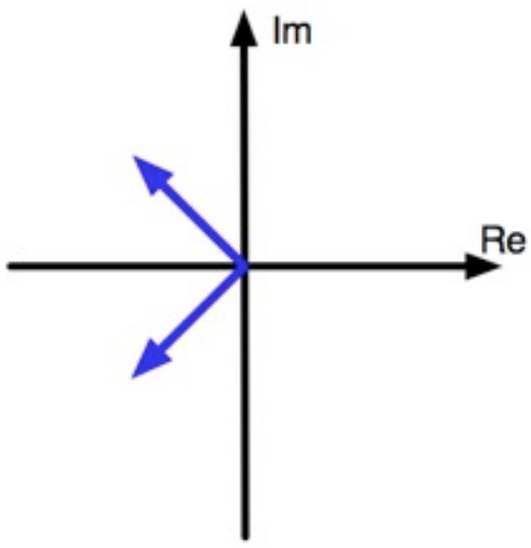
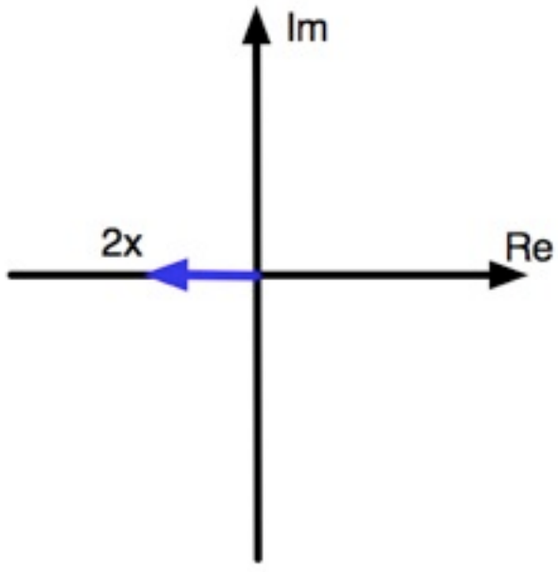
$Q > 0.5$
(underdamped)



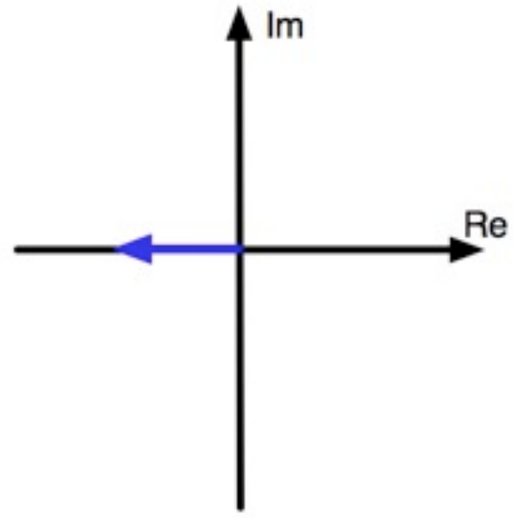
$Q = 0.5$
(critically damped)



$Q < 0.5$
(overdamped)

About poles (and zeros) notation

- Simple pole: f = 1 Hz



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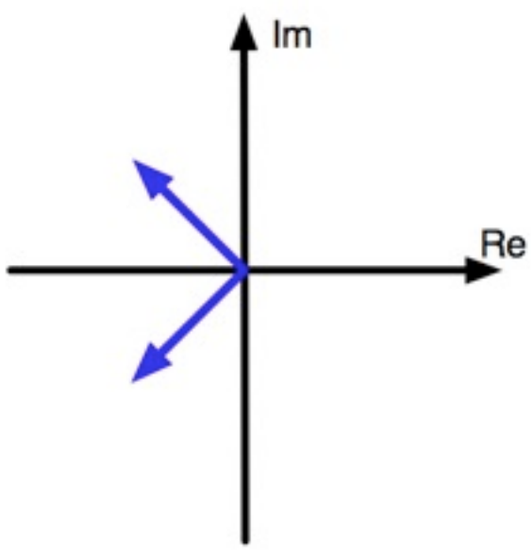

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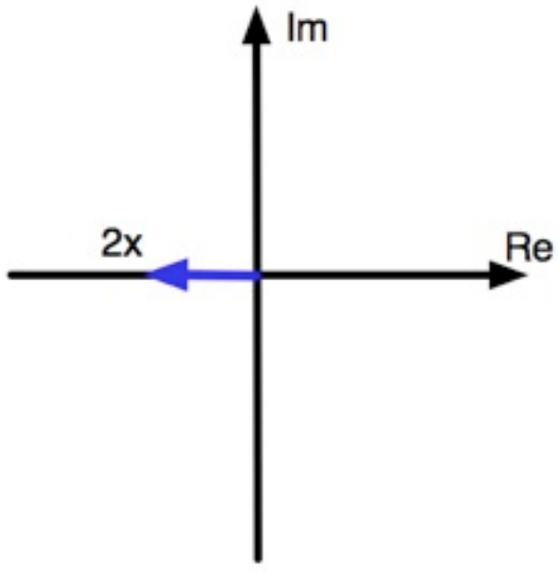
(critically damped)



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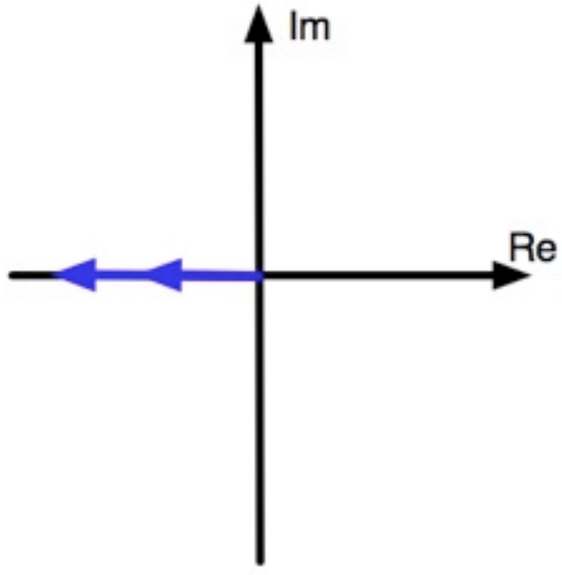
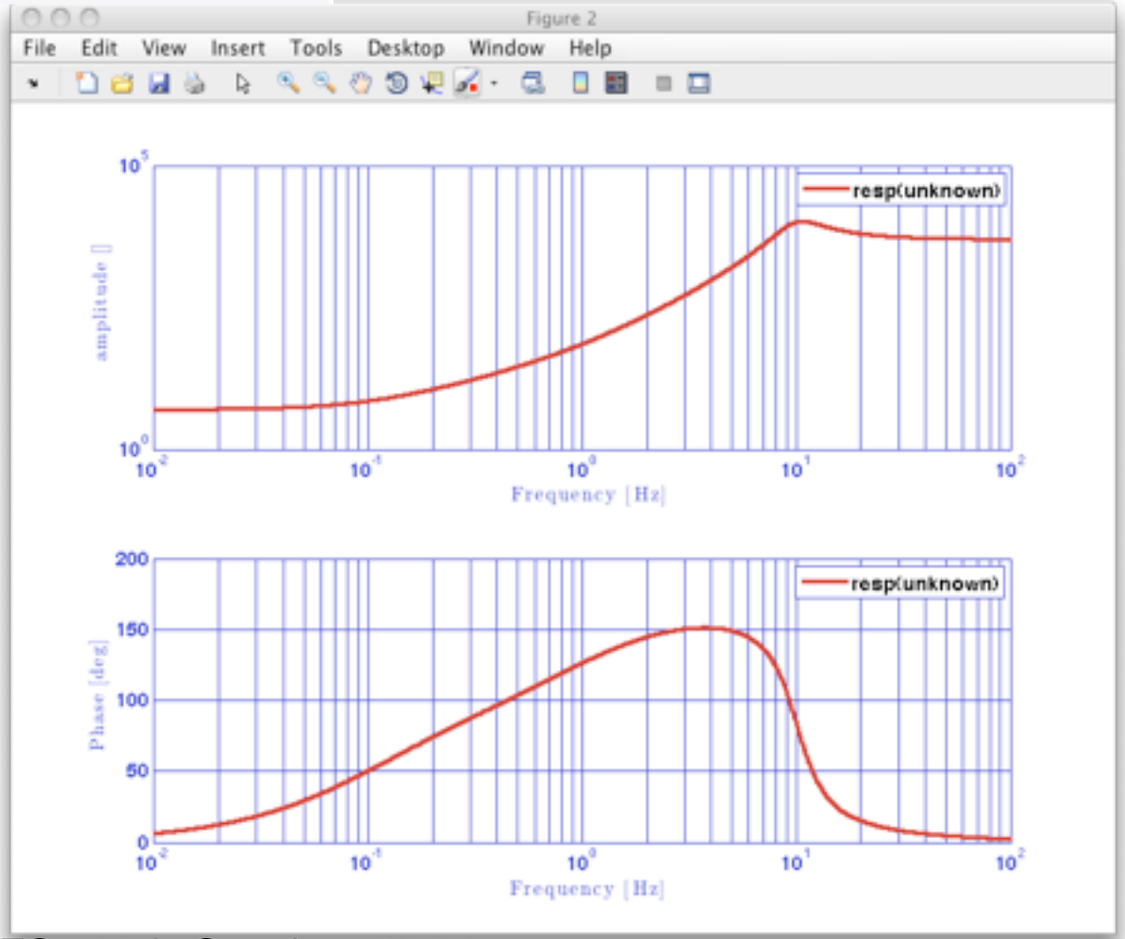
(overdamped)



Pole/zero models

- Working example: Compute pole zero response
  - Topic 4 -> Create transfer function -> Create pole zero model

Key	Value
GAIN	5
POLES	(f = 1 Hz, Q = 2)
ZEROS	(f = 1 Hz), (f = 0.1 Hz)

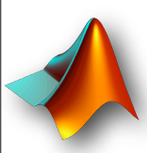


Rational models

- A rational model is defined by:
  - Num. and den. coefficients

$$H(s) = \frac{a_1\, s^m + a_2 s^{m-1} + \ldots + a_{m+1}}{b_1\, s^n + b_2\, s^{n-1} + \ldots + b_{n+1}}$$

- LTPDA constructor: RATIONAL
  - RATIONALs can NOT be multiplied and divided
- Working example: Compute rational response
  - Topic 4 -> Create transfer func... -> Create rational model

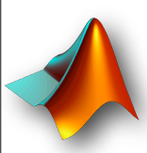


Partial-fraction models

- A partial fraction model is defined by:
  - Poles, residues and direct terms

$$H(s) = K(s) + \sum_{i=1}^{N} \frac{R_i}{s - p_i}$$

- LTPDA constructor: PARFRAC
- PARFRACs can NOT be multiplied and divided
- Working example: Compute par. frac. response
  - Topic 4 -> Create transfer func... -> Create par. frac. model



Transforming models

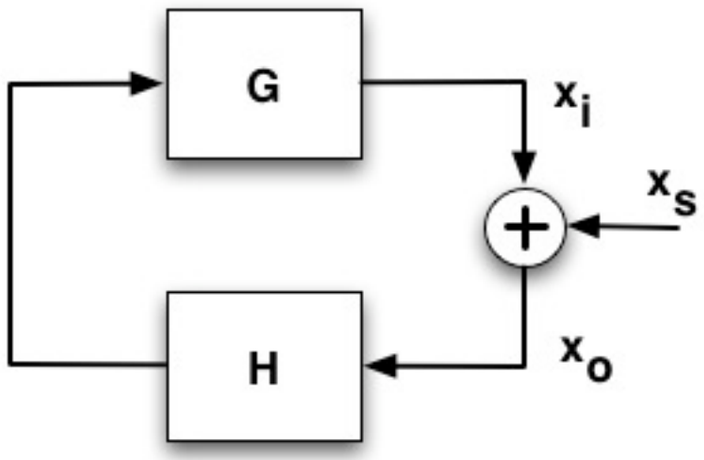
- Some of the possible transformations are implemented in v2.3
  - Works by inputting an object into a constructor
    - e.g. rat = rational(pzm)
- Working example: pzmodel -> rational -> pzmodel
  - Topic 4 > Transforming models between representations

	Pole/Zero	Rational	Partial Fraction
Pole/Zero		√	√
Rational	√		√
Partial Fraction	√	√	

Modeling a system

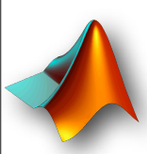
- Pole zero model
  - Modelling a closed loop system with pzmodel
  - Basic pzmodel operations

Our system:



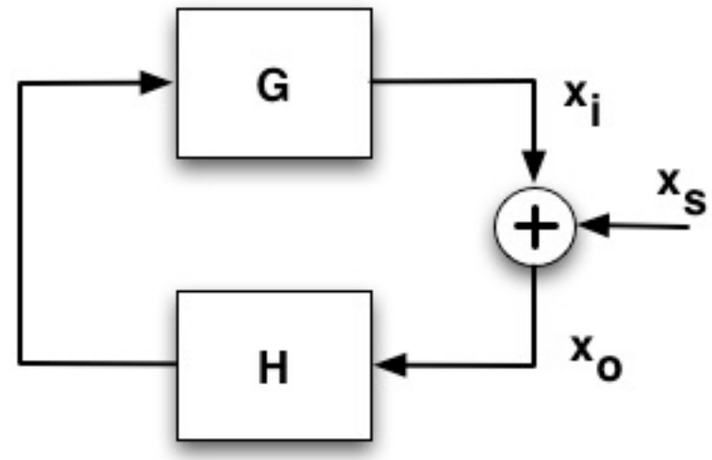
$$\frac{x_o}{x_s} = \mathrm{CLG} = \frac{1}{1-\mathrm{OLG}} = \frac{1}{1-\mathrm{H}\cdot\mathrm{G}}$$

- The problem:
  - Assuming OLG and H known, determine G and CLG



Modeling a system

- Step-by-step
  1. G = OLG/H
     (G is a pzmodel)
  2. Operate on G: setName, simplify ...
  3. CLG = 1/(1-OLG)
     (CLG is NOT a pzmodel)



$$\frac{x_o}{x_s} = \mathrm{CLG} = \frac{1}{1-\mathrm{OLG}} = \frac{1}{1-\mathrm{H}\cdot\mathrm{G}}$$

- Repeat loading H with delay

- Working example: Modeling a system
  - Topic 4 > Modeling a system

Entering the discrete domain

- The LTPDA toolbox allows you to build digital filters...
  - Discretizing your model
  - Example: find the filters for H,G, OLG in our closed loop
- Defining filter properties
  - Example: Design a bandpass filter to evaluate power spectrum in a bandwidth
- Filter constructors in LTPDA
  - MIIR (IIR filters)

$$y[n] = \sum_{k=0}^{\mathrm{N}} b[k]\, x[n-k] - \sum_{k=1}^{\mathrm{M}} a[k]\, y[n-k]$$

  - MFIR (FIR filters)

$$y[n] = \sum_{k=0}^{M} b[k]\, x[n-k]$$

By discretizing a transfer function

- Syntax: insert pzmodel into constructor

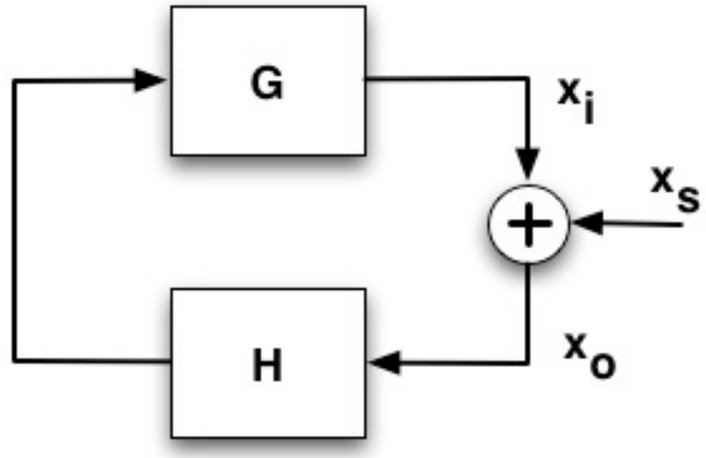
```
Gd = miir(G,plist('fs',10));
```

Constructor

pzmodel obj.

filter obj.

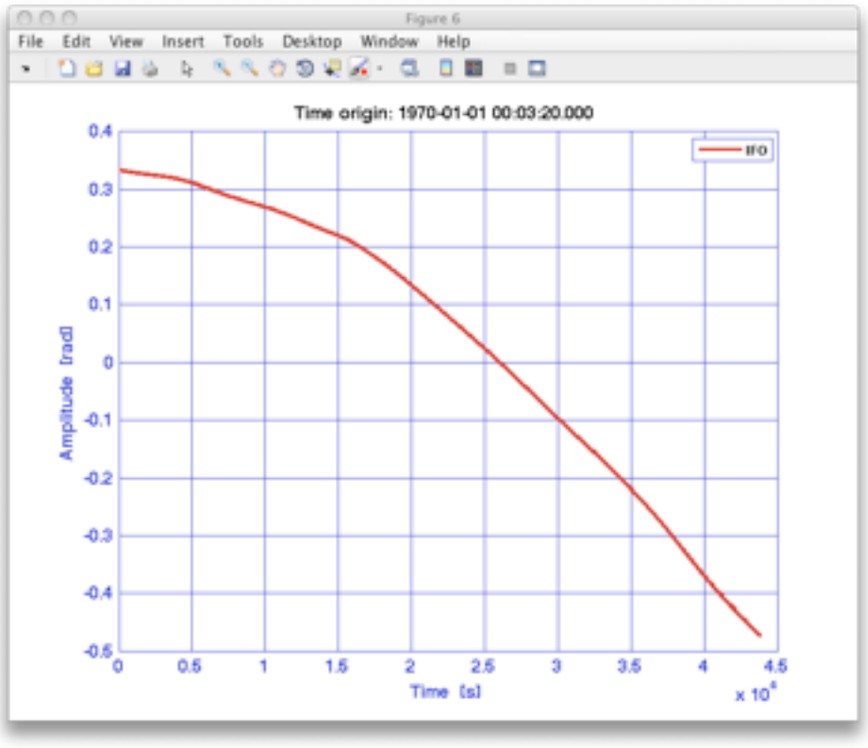
- Step-by-step
  1. Discretize G,H,OLG
  2. Compare continuous and digital respons
  3. Get filter coefficients
     - Delay is NOT used in the discretization!



- Working example: Get filters for closed loop pzmodels
  - Topic 4 > How to filter data > By discretizing...

By defining filter properties

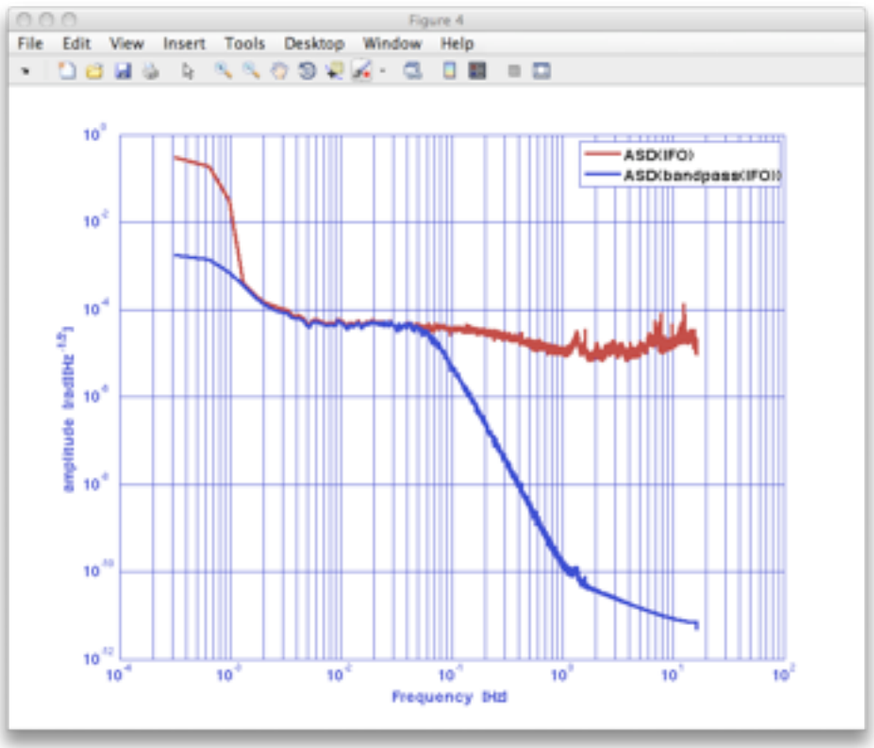
- Design a bandpass filter
  - Standard pre-processing step used in LTP lab
  - Alternative to detrending



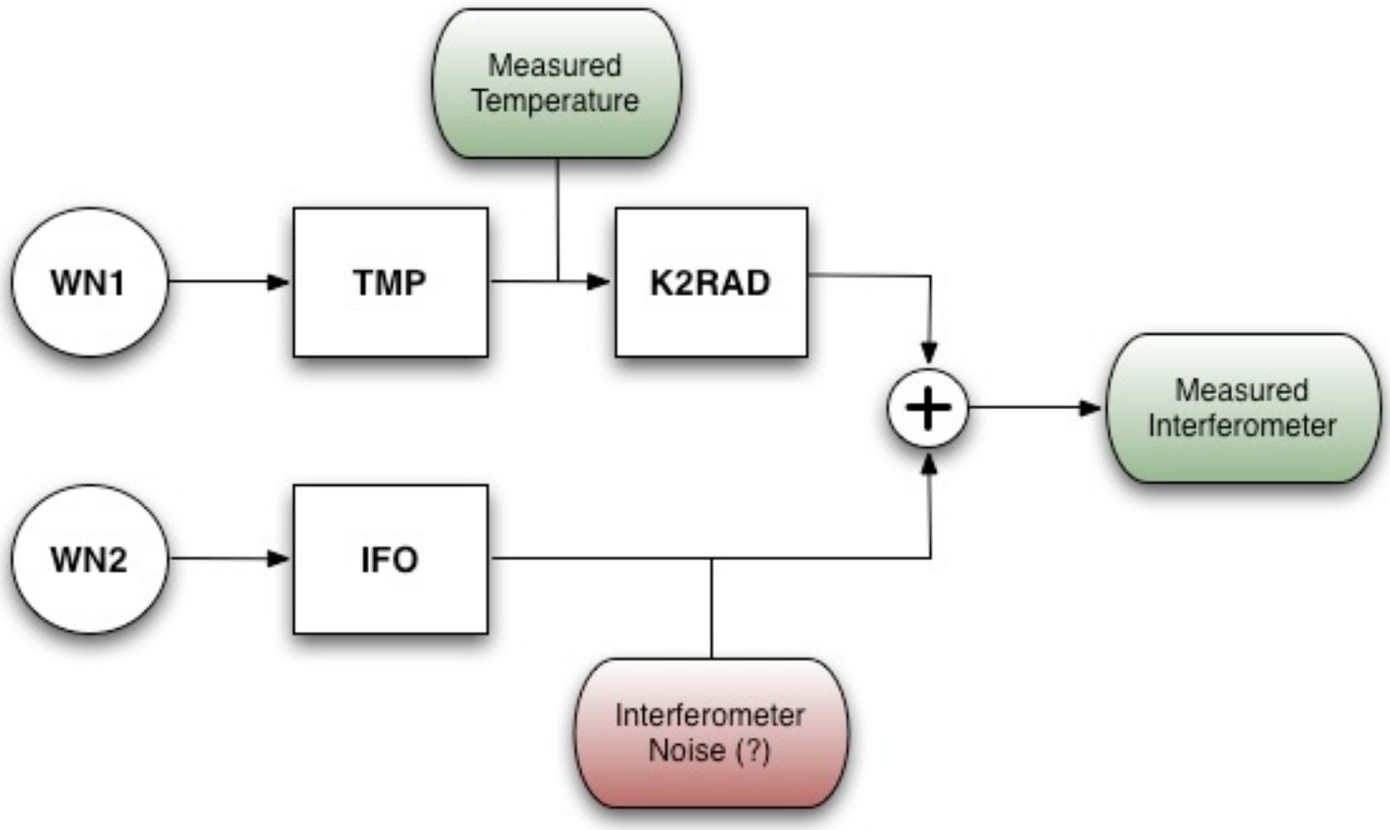
- Syntax:

```
Gd = miir(plist('fs',32.47, 'order',...));
```

- Working example: Band pass



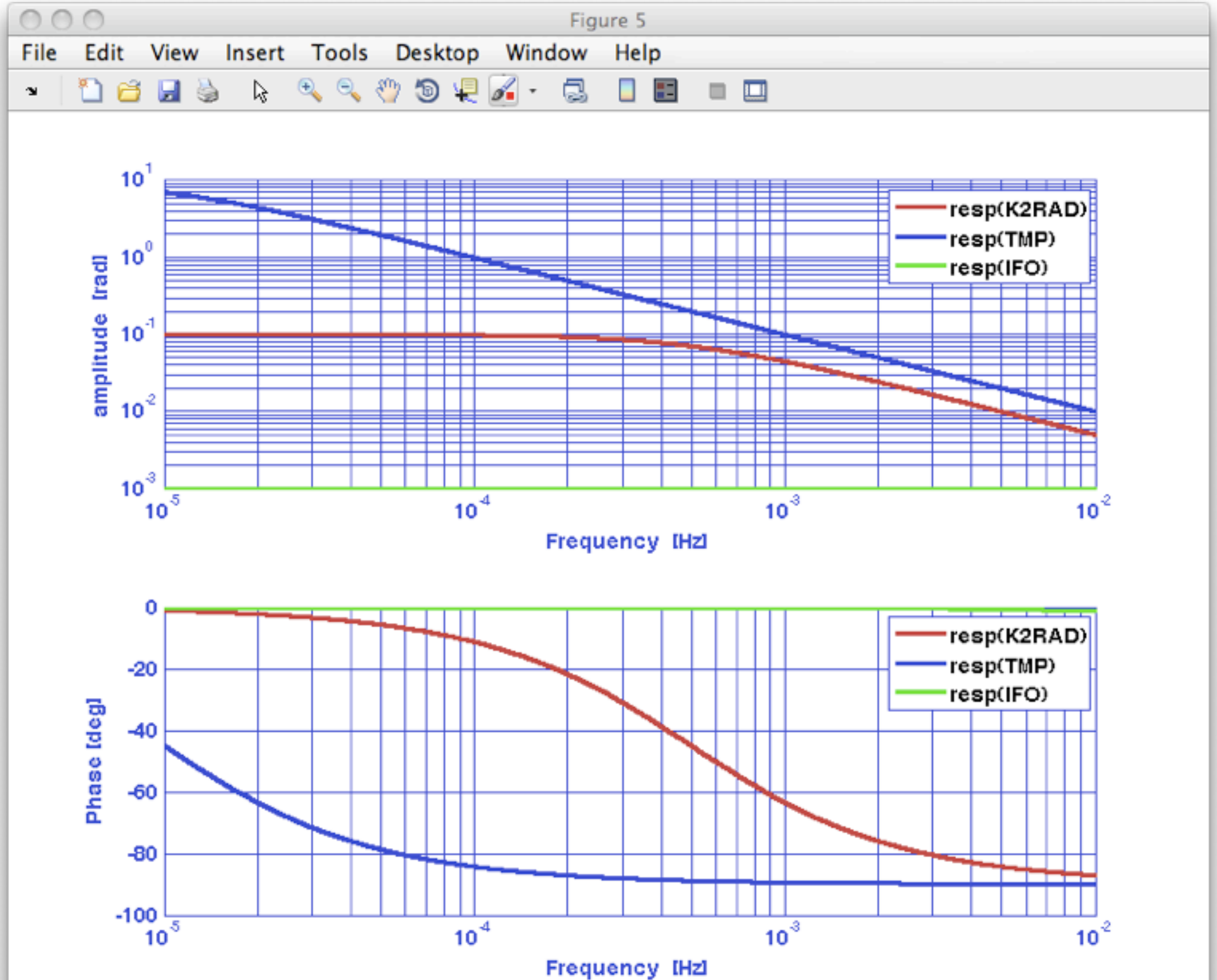
IFO/Temperature Example



- Aim: perform the analysis with a toy model
  - Create transfer function models: TMP, IFO,K2RAD
  - Discretize
  - Filter (white noise) data
  - Estimate transfer function (topic 3) with synthetic data

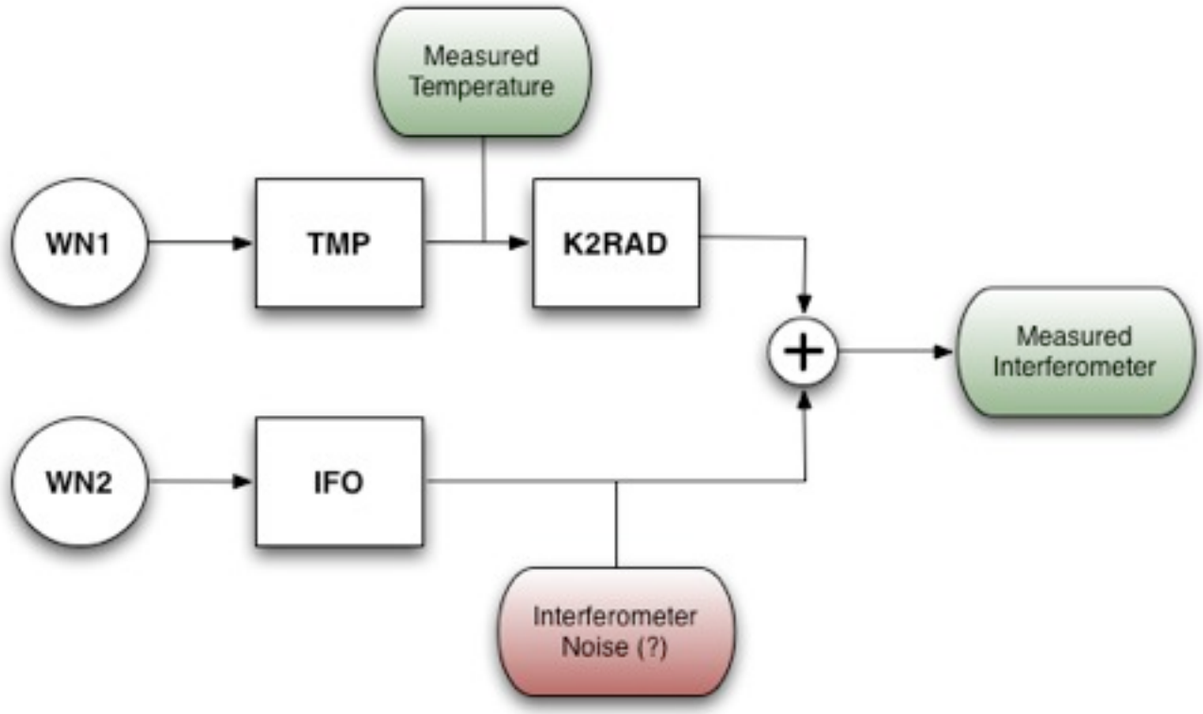
IFO/Temperature Example

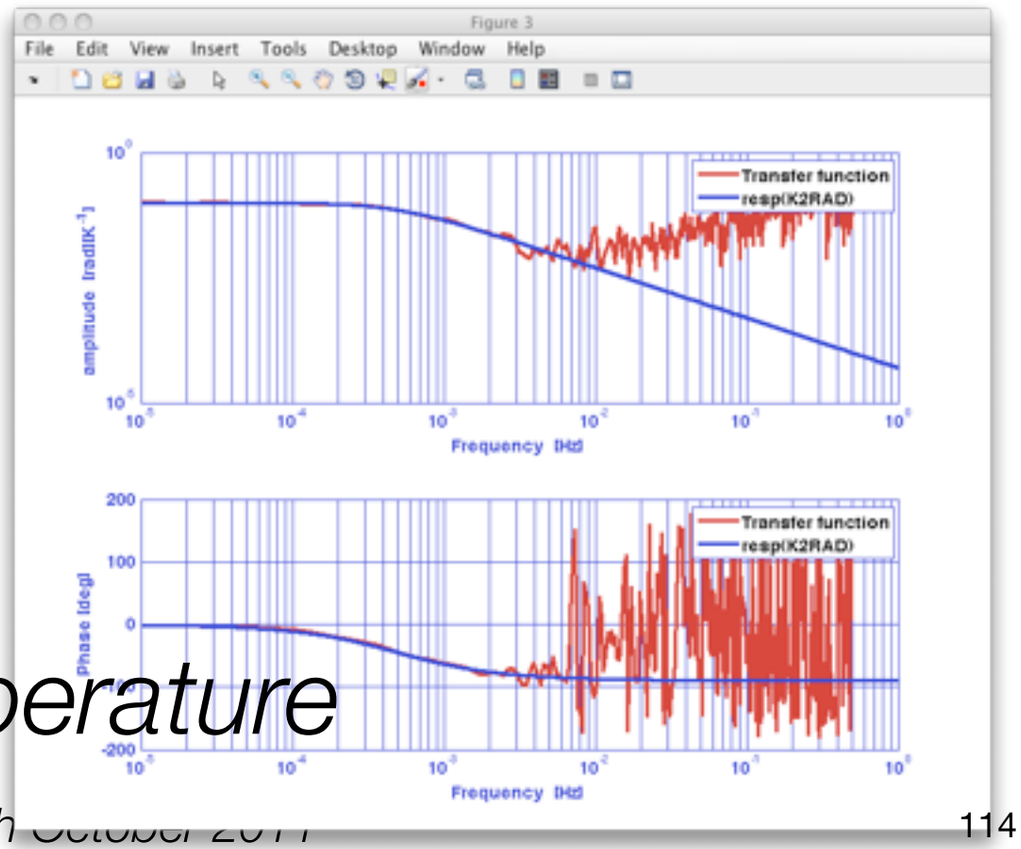
- The toy models



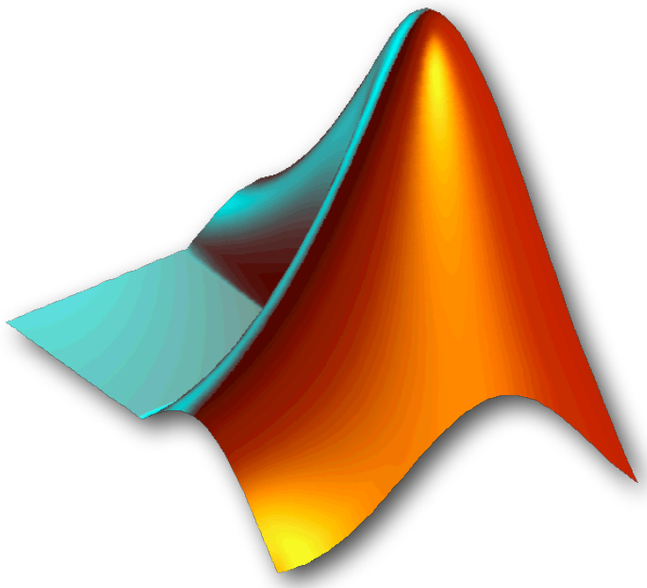
IFO/Temperature Example

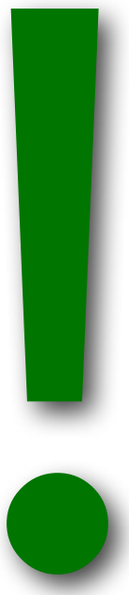
- Step-by-step
  - Generate models:
    - TMP, IFO, K2RAD
  - Discretize
  - Build two white-noise time-series
  - Filter with the digital filters
  - Estimate transfer function
  - Project temperature noise





Working example: IFO/Temperature





Topic 5: Fitting to data

- let's see if we will have time...