

The SMASH toolbox

Course overview



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Objective: more powerful and efficient data analysis using the SMASH toolbox

- This course includes
 - Some advanced MATLAB concepts
 - Core toolbox features
 - Short exercises
 - Supervised tinkering

Why MATLAB?

- Quickest path for technical computing
 - Unified environment: commands, graphics, ...
 - Comprehensive documentation
 - Math is natural, not an afterthought
- Most efficient use of your time
 - “Free” alternatives ignore labor cost
 - Subject expertise costs more than software

What is SMASH?

- Sandia Matlab AnalysiS Hierarchy
 - Data management (read files, archive results)
 - Numerical computation (smoothing, FFTs, ...)
 - Visualization (1D/2D graphs, ...)
 - User interfaces (Dialog boxes, ...)
- Goals
 - Share code, analysis, and results
 - **Don't start from scratch every time**

What's inside?

- Utilities: toolbox assistance
- Programs: self-contained code, graphical interface
- Packages: general-purpose code grouped by topic
- System requirements
 - MATLAB 2017b or later suggested
 - Mac, Windows, or Linux
 - No Mathworks toolboxes are needed*

Toolbox installation

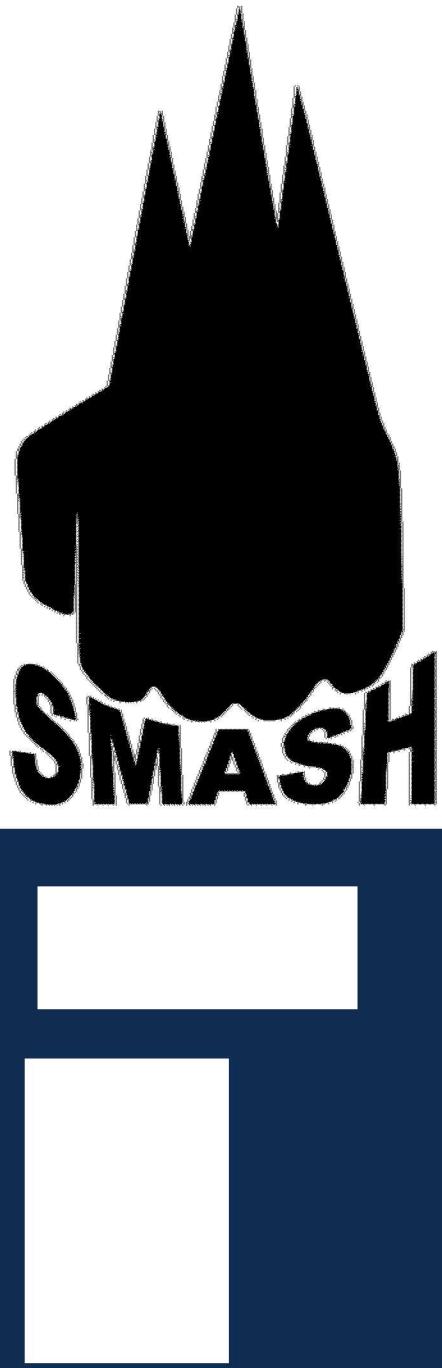
- Internal gitlab (<https://gitlab.sandia.gov>)
 - **Download ZIP or clone Git repository**
 - External GitHub also available
- Navigate MATLAB to toolbox directory
 - Run `install/installSMASH` function
 - Modifies current session path
 - Start up file for future sessions
- Verify install
 - `smashroot` command

Getting help

- When in doubt, type:
 - `help SMASHtoolbox`
 - `doc SMASHtoolbox`
 - Tab completion is your friend
- Additional resources
 - `readme.md` file on gitlab/GitHub page
 - Internal wiki (Sandiapedia)
 - Version 1.0 manual (SAND2016-6848)
 - User meetings

Course Agenda

- Utilities, programs and **packages**
- Arrays, structures, and **objects**
- Signal analysis
- File access
- Image analysis
- Individual projects
 - Suggested features or things that interest you



The SMASH toolbox

Utilities, programs, and packages



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Utilities versus programs

- Utility functions help access the toolbox
 - smashroot
 - SMASHtoolbox
 - loadSMASH
- Programs are MATLAB code with:
 - Specific purpose and a graphical interface
 - Formal distinction can be ambiguous, but it's usually obvious in practice

SMASH programs

- Located in (smashroot)/programs folder
 - Separate folders for each program
 - Usually a main function with a private folder (where most of the code resides)
 - May or may not reference other parts of the toolbox
 - Some predate the toolbox by 5-10 years
 - Many toolbox features drawn from the older programs

Exercise

- Use the SMASHtoolbox utility
- Run the MCdemo program to estimate the value of pi
 - Use the start, pause, and reset features
 - How many iterations are needed to ensure at least two-digit accuracy? What about three digits?

Using programs (continued)

- Programs can be launched directly **if** they are on the MATLAB path
 - `loadSMASH -program (name)`
- Some programs behave like ordinary functions when inputs are passed

Exercise

- Load MCdemo on the MATLAB path
- Call MCdemo from the command window
 - Read the program's help entry
 - Bypass the graphical interface interface to quickly run one million iterations

Program survey

- Analysis:
 - PointVISAR (VISAR reduction)
 - SIRHEN and THRIVE (PDV/PDI reduction)
- Synthetic data
 - pyrosim (pyrometer simulator)
 - fringen (VISAR/PDV fringe generator)
- Other tools
 - datninja (digitize figure data)
 - SDAbrowser (Sandia Data Archive support)

MATLAB packages

- Folders begin with a plus sign: `/+mytools`
- Anything inside the package can be accessed with dot notation
 - `[...] = mytools.functionA(...)`
- Packages can be nested within packages
 - `[...] = mytools.subpack.functionA(...)`

Example: checkDisplay function

- SMASH.Graphics.DisplayTools.**checkDisplay**
 - SMASH package
 - Graphics subpackage
 - DisplayTools subpackage
 - checkDisplay function
- Tab completion is your friend!

Are all those dots really necessary?

- Import packages to workspace

```
loadSMASH -package Graphics.DisplayTools.*
```

- Import packages as a name space

```
name=loadSMASH ('-package', ...  
  'SMASH.Graphics.DisplayTools.*');  
name.CheckDisplay()
```

- Similar to Python “import as”

- Note: empty parenthesis are important

- MATLAB also has its own import command, but I
don’t recommend it

Most toolbox code resides in packages

- +SMASH
 - +SignalAnalysis
 - +FileAccess
 - +ImageAnalysis
 - Much, much more...

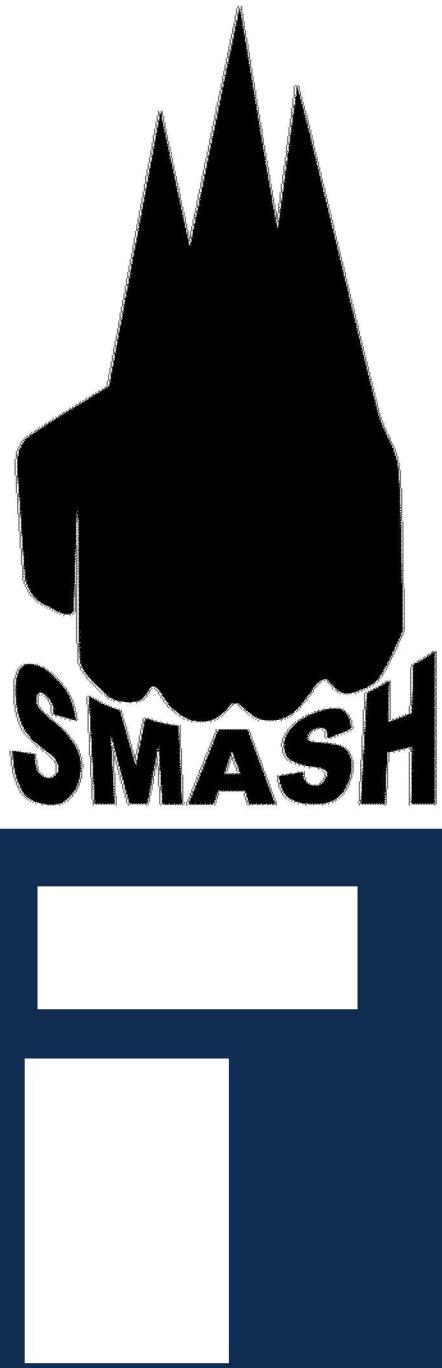
Exercise: the Reference package

- Locate the Reference package
- Find the PhysicalConstant function
- Look up the value of hc
 - Plank's constant times the speed of light
 - Roughly 1240 eV*nm
 - Convert 532 nm to photon energy

$$E = \frac{hc}{\lambda}$$

Summary

- Programs are:
 - Self-contained code with graphical interface
 - Added to the path
- Packages are:
 - Organized directories starting with a “+” sign
 - Called with dot notation or imported
- **loadSMASH is your friend**



The SMASH toolbox

Array, structures, and objects



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Numeric arrays are natural in MATLAB

- **Exercise:**

- `time=linspace(0,1,50);`
- `signal=cos(2*pi*5*time);`
- `plot(time,signal)`

What about metadata?

- Information about the data
 - When/where was it taken?
 - What equipment was used?
 - General notes, ...
- Information can be stored as separate variables
 - Very fragile

Compound variables

- Mix data of different type/size in a single variable
- Cell arrays (curly braces)
 - Data indexed by number
 - `data{1}`, `data{2}`, ...
- **Structures**
 - Data indexed by name

Exercise: structured data

- Store data
 - `data.Time=linspace(0,1,50);`
 - `data.Signal=cos(2*pi*5*time);`
- Store metadata
 - `data.Date='March 29'`
 - `data.Equipment='Fancy digitizer'`
- Structure fields can be used like any other variable
 - `plot(data.Time, data.Signal)`

Object oriented programming (OOP)

- Custom data type that defines
 - Properties (where information goes)
 - Methods (operations that can be performed)
- What's the difference?
 - Properties are things (**nouns**)
 - Methods are actions (**verbs**)

Why bother with objects?

- Data can be protected from the user
 - Enforce types (numeric, character, etc.)
 - Controlled names (can't put something in the wrong place)
- Methods know where the data is and are context-aware
 - `view(A)` uses view method for object A
 - `view(B)` uses view method for object B
 - A and B may be different classes altogether...

Notation

- Properties accessed with dot notation
 - `value=object.Name`
 - `object.Name=value % (if allowed)`
- Two ways for accessing methods
 - `[...]=view(object,...) % MATLAB style`
 - `[...]=object.view(...) % most languages`
 - Generally produce identical results

Exercise: Signal class

- Class defines object properties and methods
 - Object is an instantiation of the class
- Object construction
 - `object=Signal(time,signal)`
 - NOTE: class resides in SMASH.SignalAnalysis package, so dot notation or package import is required

Learning about an object

- Help/doc statement on class name (including package location)
 - `help(object)` or `doc(object)` also works
- Command window displays a hyperlink whenever object is called without a semicolon
- Browsing properties/methods helps understand what a particular class does

Summary

- Data can be managed with
 - Numeric arrays (plus extra variables)
 - Compound arrays (structures)
 - Custom objects
- Object oriented programming (OOP)
 - Properties store information, enforce limits
 - Methods are context-specific functions
 - **Goal: guide and reign in the end user**

You do not have to be able to write an object class to benefit from using objects



The SMASH toolbox

Signal analysis



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What is a Signal?

- One-dimensional (scalar) data defined on a one-dimensional grid
 - Digitizer records: grid is time, data is voltage
 - Spectrometers: grid is wavelength, data is power/counts
- Grid may or may not be uniformly spaced
 - Must be monotonically increasing/decreasing
 - Values must be unique

Learning about the Signal class

- doc SMASH.SignalAnalysis.Signal
 - Class overview
 - Object construction
 - Property descriptions and permissions
 - Method documentation

Creating a Signal object

- Existing MATLAB variables
 - `object=Signal(grid,data)`
- View method creates a plot
 - `view(object)`

Exercise

- Create a sinusoid
 - `x=linspace(0,1,80);`
 - `y=cos(2*pi*10*x+2*pi*rand(1));`
 - Use the `view` command to display plot
- Modify `GridLabel` and `DataLabel` properties for the sinusoid object
 - Suggestions: ‘Time (ns)’ and ‘Signal (V)’
 - Call `view` method

Grid and Data properties

- Read-only access
 - `x=object.Grid` is valid
 - `object.Data=y` is invalid
- Reset method allows manual overwrite
 - `object=reset(object,x,y);`
 - Faster than creating a new object

Grid/Data modifications

- Shift/scale methods modify the grid
 - `object=scale(object,value)`
 - `object=shift(object,value)`
- Object arithmetic automatically applied to Data
 - `object=object+1;`
 - `object=2*object;`

Exercise

- Convert sinusoid time base from nanoseconds to seconds
 - Scale by $1e-9$
- Shift grid by $42e-9$ s
- Multiply data by ten
- Plot the results

Other grid modifications

- Crop removes information outside bounds
 - `object=crop(object,bound);` % irreversible
- Limit method focuses inside a bound
 - `object=limit(object,bound);` % reversible
- Regrid changes grid and interpolates data
 - `object=regrid(object,new);` % irreversible
 - `object=regrid(object);` % uniform grid

Fourier transforms

- Convert from time/space to frequency domain
 - `new=fft(object);` % result is a Signal object
- Extra inputs define transform options
 - `new=fft(object,'RemoveDC',true);`

Exercise

- Calculate the power spectrum of the sinusoid object
 - Where is the peak located?
- Increase the number of frequencies for a smoother result
- Generate the complex power spectrum
 - How does the view method handle this?

Documenting your work

- Name property is for short tags
 - Example: 'Experiment TK421'
- Comments property is for verbose description
 - `object=comment(object); % editor window`
- No size restrictions in either case
 - Values must be text

Summary

- Signal objects describe scalar data on a 1D grid
- Grid/Data properties cannot be set directly
 - Can be modified with scale, shift, reset, ...
 - Arithmetic support for Data
- Methods provide visualization, transforms, and much more



The SMASH toolbox

File access



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Overview

- Getting data into MATLAB
 - FileAccess package
- Storing data
 - Sandia Data Archive (*.sda) files

FileAccess package supports many formats

- Text files
 - 'column' : numeric columns with arbitrary header
 - 'block' : numeric column blocks separated by headers
- Digitizer files : 'agilent'/'keysight', 'tektronix', 'lecroy', ...
- Image files
 - 'film' densitometry scans
 - 'standard' graphic formats (*.jpg, *.png, ...)
 - Various camera formats ('optronis', 'winspec', ...)
- Laboratory binary files
 - 'dig' digital signals from NTS
 - 'pff' Portable File Format (legacy Sandia format)
 - 'sda' Sandia Data Archives

doc SMASH.FileAccess.SupportedFormats

Raw data import

- `data=readFile(file,format,record)`
 - Format and record may be optional, depending on file type
 - Some formats have a unique file extension, others do not
 - Returns a structure
- Files can be probed without reading
 - `report=probeFile(file,format)`

Exercise: tabular data

- Read the file “table.txt”
 - Hint: use ‘column’ format
 - Plot columns 2-3 versus column 1
- Probe the same file
 - Verify the number of header lines and columns

Exercise: binary data from a digitizer

- Read the file “shot_Ch1.wfm”
 - Hint: file came from a Tektronix digitizer
 - Plot signal
- Probe the file “Z2576_T10_SHOT.h5”
 - Hint: file came from an Agilent digitizer
 - How many signals are in this file?
- Read the file “Z2576_T10_SHOT.h5”
 - One record at time
 - All at once

Signal class automatically calls readFile

- `object=Signal(file,format,record)`
- **Exercise:**
 - Create object from “table.txt”
 - Which columns are loaded?
 - Create object from “shot_Ch1.wfm”
 - Create object from “Z2576_T10_SHOT.h5”
 - Which record is loaded?
- Many SMASH classes behave this way...

Saving data

- Some classes provide an export method
 - Usually a text dump
 - Metadata usually lost
- Sandia Data Archive (*.sda) files are a more powerful alternative
 - Any MATLAB variable (arrays, structures, objects, ...)
 - External files (documentation, ...)

SDA overview

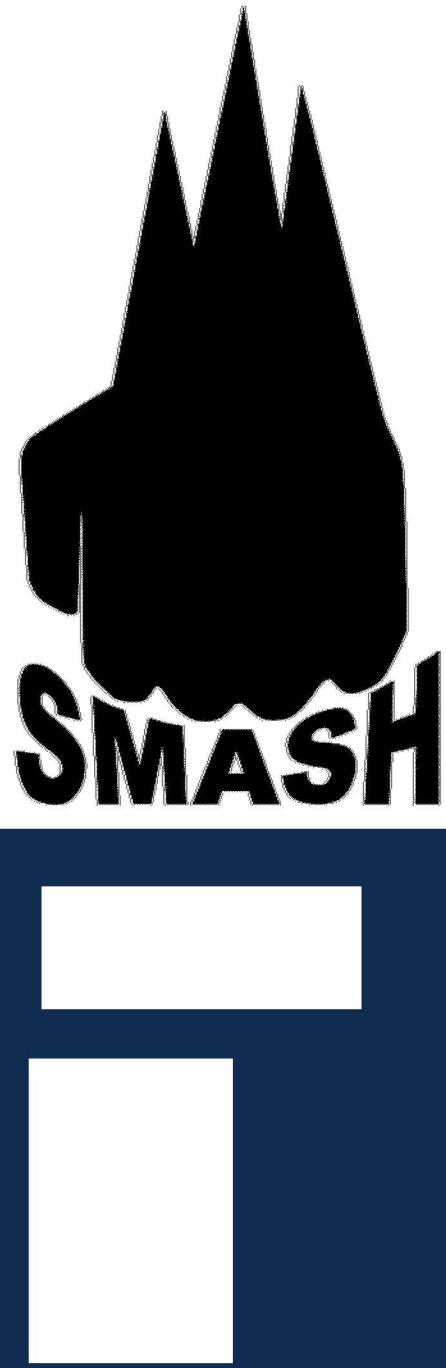
- Based on HDF5 standard
 - Portable across platforms/languages
 - SDA-specific Python library available
 - Better documented than MAT files
- Each variable associated with a unique text label and optional description
- Lossless compression available (deflate 0-9)

SDAbrowser program

- **Exercise**
 - Run the SDAbrowser program
 - Create a new archive file
 - Save Signal object(s) to archive
 - Clear workspace
 - Restore object(s) to workspace

Summary

- FileAccess package can read many text and binary formats
 - `readFile`, `probeFile` functions
 - Some classes call `readFile` automatically
- Sandia Data Archives (*.sda files)
 - Portable format for storing records
 - Unique labels (order doesn't matter)
 - Supports **any** MATLAB variable*



The SMASH toolbox

Image analysis



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What is an Image?

- One-dimensional (scalar) data on two one-dimensional grids
 - Gray scale image: grid1/grid2 are position, data is counts
 - Spectrograms: grid1 is time, grid2 is frequency, data is power
- Similar conventions as Signal
 - Uniform spacing (or not), monotonic grids, ...

Learning about the Image class

- doc SMASH.ImageAnalysis.Image
 - Class overview
 - Object construction
 - Property descriptions and permissions
 - Method documentation

Creating an Image object

- Existing MATLAB variables
 - `object=Image(grid1,grid2,data);`
 - Grids are 1D arrays, data is a 2D array
- Data stored in a file
 - `object=Image(file,[format],[record])`
 - No input launches interactive mode
 - Format/record may be optional, depending on the file type

Exercise

- Create a 2D Gaussian
 - `x=linspace(-2,2,100); y=x;`
 - `[X,Y]=meshgrid(x,y);`
 - `object=Image(x,y, exp(-X.^2-Y.^2));`
- Use view method to see results
 - `view(object)`

Exercise

- Create an Image object from Sandia logo
- Use the view method and fix the aspect ratio
 - Hint: look at GraphicOptions property OR MATLAB's “axis” command

Why are Images displayed upside down?

- MATLAB puts the origin in the upper left corner
 - Common in a lot of image processing
 - Matrix convention
- This can be changed by modifying the `GraphicOptions` property
 - `object.GraphicOptions.YDir='normal';`
 - `view(object)`
- Lots of other graphic options (color map, ...)

Exercise

- Images have three view modes
 - “show” mode used by default
- Apply the other two view modes on the 2D Gaussian image

Close parallels between Image and Signal

- There are two grids to deal with
 - `object=scale(object,'Grid1',value);`
 - `object=shift(object,'Grid2',value);`
- Arithmetic operations apply to data (2D)
 - `object=2*object+1`
- Some methods accept two grid inputs
 - `object=crop(object,xb,yb);`

Image orientation

- Flip grid direction
 - `object=flip(object,coordinate);`
- Direction or angle rotation
 - `object=rotate(object,'left');` % 90 degrees
 - Reversible
 - `object=rotate(object,value);` % any angle
 - Irreversible

Exercise

- Use interactive rotation mode on MATLAB's default image
- Interactively crop the result around the face

Image slicing

- Extract data at fixed grid1/grid2 location(s)
 - `result=slice(object,'Grid1',x);` % vertical
 - `result=slice(object,'Grid',y);` % horizontal
- Slices are SignalGroup objects
 - All class methods (view, etc.) are available

Exercise

- Slice the Sandia logo at several locations
- Interactively slice that image
 - Hint: read the documentation

Other Image methods

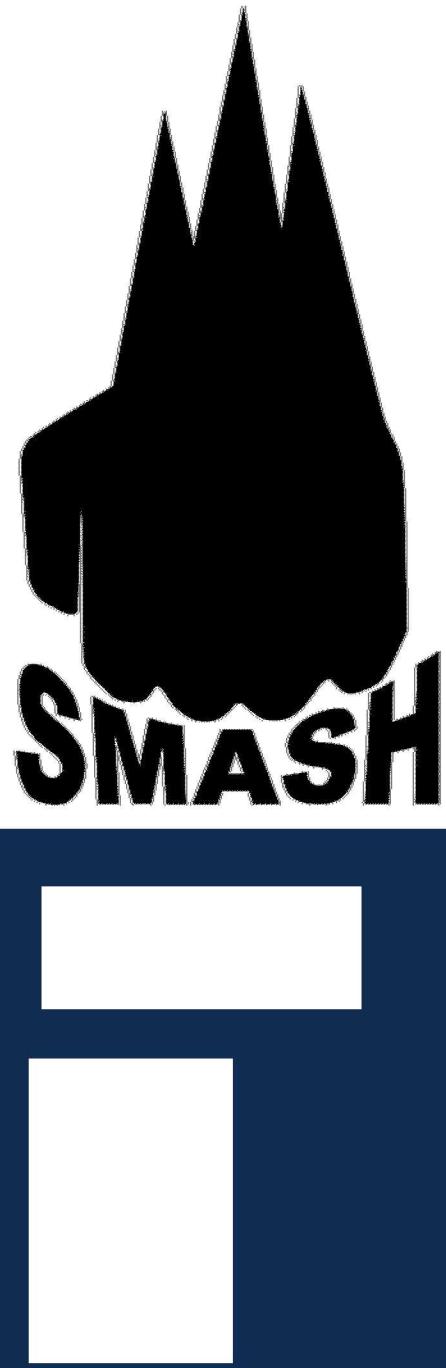
- bin: combine local blocks into super-pixels
- smooth/sharpen: low/high-pass filtering
- center: adjust grid origin
- register: adjust grid/data to master image
- ...and much more!

Storing Image objects

- Export method dumps [x y z] values to a text file (not recommended)
 - Huge file sizes
 - Metadata lost
- Image/ImageGroup objects are fully SDA compatible
 - Retains data and metadata

Summary

- Images describe scalar data on two 1D grids
 - Camera measurements
 - Spatial grids
 - Time/wavelength grids, ...
- Similar to Signals, with extra features
 - Multiple visualization modes
 - Rotation
 - Slicing



The SMASH toolbox

Toolbox summary



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The SMASH toolbox provides

- **Utilities**
 - Code that makes the toolbox easier to use
 - SMASHtoolbox, loadSMASH,...
- **Programs**
 - Self-contained code, graphical interface, specific purpose
 - MCdemo, datninja, ...
- **Packages**
 - Everything else

Core packages

- Signal and image analysis
- File access
- Other core packages
 - MUI
 - Graphics
 - System
 - General



Other general packages

- Arbitrary curve fitting
- Statistics (Monte Carlo and Bayesian)
- Reference (physical parameters, ...)
- Journal (publication figures, tables, ...)
- Region Of Interest selection
- And more...

Specialized packages

- Instrument (digitizer control,)
- DynamicMaterials (EOS calculations ...)
- Spectroscopy analysis (pyrometry, ...)
- Velocimetry analysis (VISAR, PDV, ...)
- Xray analysis (imaging and diffraction)
- Z data (DAS signals, SVS data, ...)

Getting involved

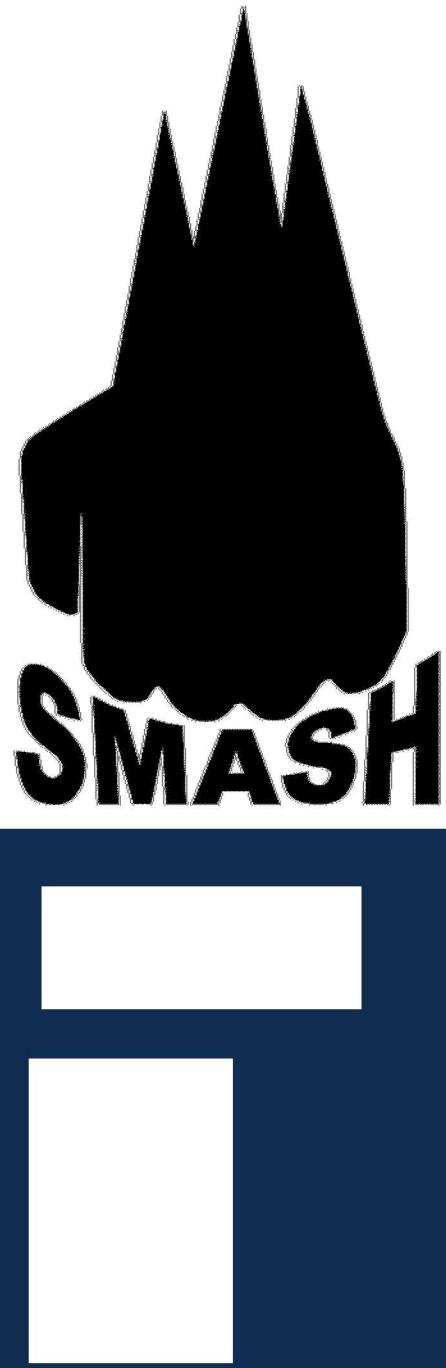
- Step 1: set up Git for version control
- Step 2: find a problem that interests you
- Step 3: figure out how this fits into the toolbox
- Step 4: **work safely**
- Step 5: commit/push/pull often (Git)
- Step 6: Participate in the user/developer meetings

Work safely

- Don't modify core features (w/o checking)
 - Bug fixes and new features OK
 - Established behavior should be preserved as much as possible
- Use **meaningful** names
 - Properties use camel case: PeakLocation
 - Methods/functions use mixed case: findPeak
- Document your code (how is it supposed to work?)
- Avoid binary files in the repository*

We are always open to feedback

- Bug reports and feature requests
 - Submit to GitHub repository (Issues tab)
- Open discussion
 - Community forum on SMASH wiki
- **Limited** consulting for toolbox additions
 - Priority is experimentalist needs in 1600 (dynamic compression, plasma physics, pulsed power, ...)



The SMASH toolbox

Individual project suggestions



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Project idea: Digitize figure data

- Call the datninja program
- Digitize the file “ScannedFigure.png”

Project idea: Monte Carlo analysis

- Use the MonteCarlo.Cloud class to generate two random variables (x,y)
 - Use mean 0, variance 1
 - View cloud (standard and raw mode)
- Transform data to a new cloud
 - $u=x-y$; $v=x+y$
 - $u=x.^*$; $v=x.^2 + y.^2$;
- Compare transformed clouds to original
 - Correlation
 - Normality

Project idea: Curve fitting

- Load (x,y) data from the “NoisyPeak.txt” file
 - `data=readFile(filename, 'column');`
 - `data=data.Data;`
- Create a Curve object with Gaussian basis function
 - Hint: $\text{@}(p,x) \exp(-(x-p(1)).^2/(2*p(2)^2)$
- Optimize curve to fit data
 - Plot fit with data
- Analyze parameter uncertainty
 - Determine 90% confidence region

Project idea: Short-time analysis

- Generate a sinusoid with variable frequency
 - $S(t)=\cos(2\pi 10t + 50\pi t^2)$ for $t=[0, 1]$
- Create a STFT object from this data
- Partition the data into 0.2 time durations, advancing 0.01 between each duration
- Use the analyze method to generate a spectrogram
 - View the results

Project idea: dialog boxes

- Start with MATLAB's `inputdlg` command
 - Ask the user for their name, quest, and favorite color
- Use the `MUI.Dialog` class to mix edit boxes with popup menus
- Add “OK” button that checks answers **before** closing the dialog