CosmoSIS Webinar 2

Advanced sampling and creating new cosmological pipelines

Presenting for the CosmoSIS team:
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Currently in cosmology we have a few challenges:

- Many, sometimes correlated, **observables**:
  -CMB, lensing, galaxy clustering, supernovae, clusters…..

- Different **theoretical models**:
  -e.g. Supernovae light curve fitters, bias models for galaxy clustering

- Different **parameters, systematics** in each model:
  -how to sample over each in an MCMC chain?

- Complicated, possibly multimodal, **Posterior/ Likelihoods**:
  -sampling choice may impact results, estimate/model covariances

- Large **collaborations** (hundreds of people e.g. (DES & Planck)):
  -how to track contributions, ensure reproducibility & consistency
  -how to use wealth of existing code/data without wasting PhD deciphering it all, learning new coding language…

CosmoSIS was designed to address each of these issues!

CosmoSIS is a new cosmology parameter estimation code with a focus on *modularity*

- Open source code which community actively contributes to
- multi - language modules: Python, C++, C, Fortran
- choice of physics & likelihood modules
- collection of samplers - mostly in python
- nice python plotting functions

Overview

- **Advanced samplers** - presented by Elise Jennings
- CosmoSIS Overview
- Writing parameter files
- Storing data in CosmoSIS DataBlocks
- CosmoSIS Modules
- Modifying Existing Modules
- Sharing, documenting, contributing, and credit

Sampling beyond Metropolis-Hastings…

Speeding up time to convergence always a goal of any sampler, esp important with increasing number of parameters

- Some issues/stumbling blocks with standard MCMC:
  - Initial distribution of points
  - choice of proposal distribution
  - parallelizing stepping algorithm
  - getting Bayesian Evidence

generally done according to priors

Large impact on time to convergence

Some interesting features of alternative samplers

- Nested sampling (Skilling 2004) -> MultiNest
  http://ccpforge.cse.rl.ac.uk/gf/project/multinest/
- Ensemble sampling -> e.g. in emcee http://dan.iel.fm/emcee/current/
- Clustering algorithms -> Kombine
- Parallel tempering for initial distribution
- Hamiltonian Monte Carlo
- Population Monte Carlo PMC
- Adaptive MCMC -> e.g. in PyMC https://github.com/pymc-devs/pymc
- Fast/Slow sampling -> e.g. in CosmoMC
- Snake, Minuit, Maxlike, grid
- Approximate Bayesian Computation, ABC

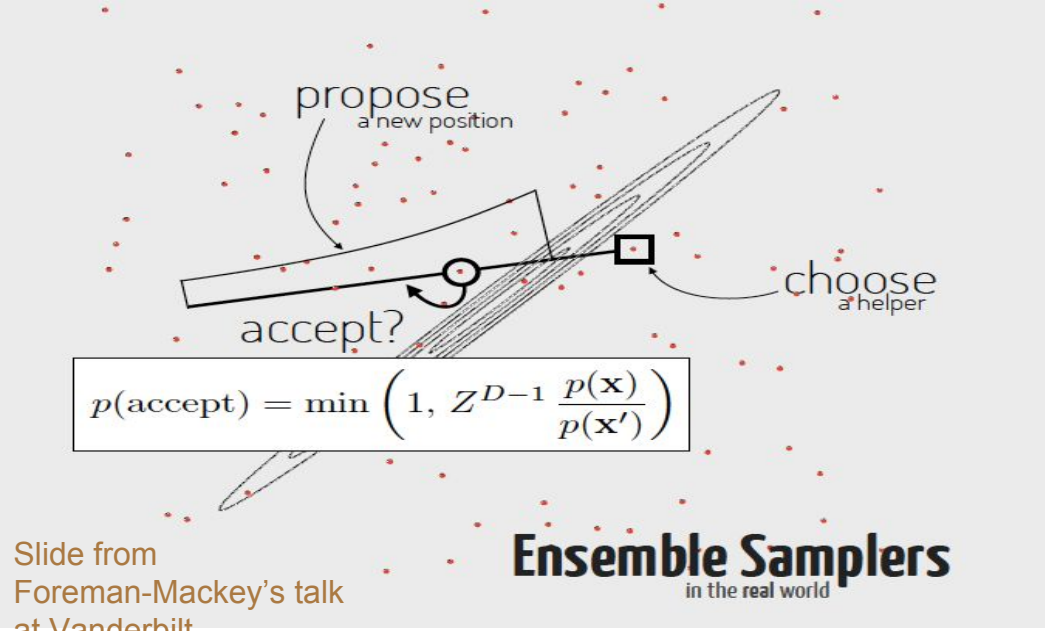
In CosmoSIS !

emcee
The MCMC Hammer

Foreman-Mackey et al 2014

- Ensemble sampler, uses “walkers” to probe parameter space

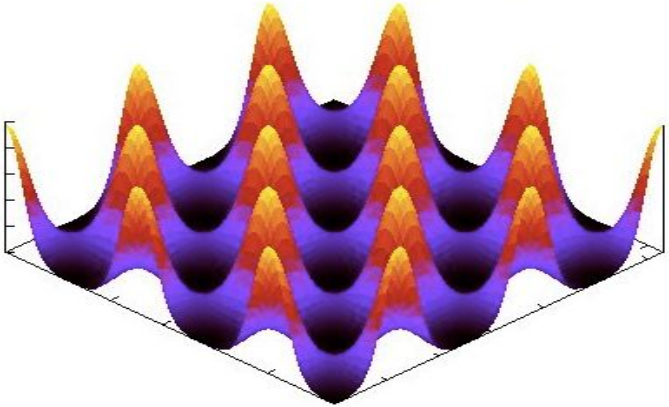
- See also the Kombine sampler in CosmoSIS

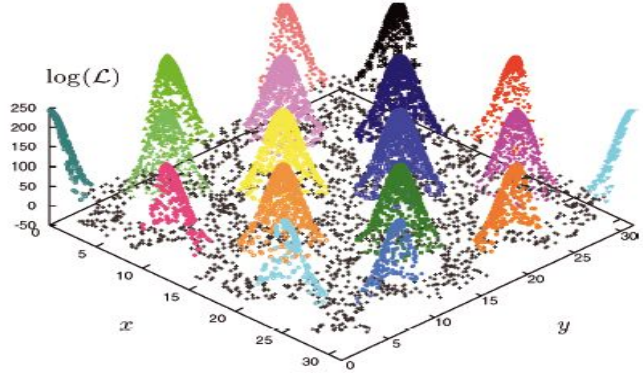


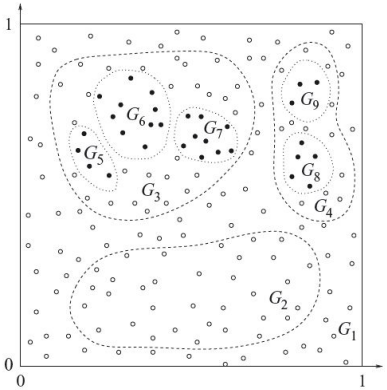
Slide from Foreman-Mackey’s talk at Vanderbilt

MultiNest

Efficient and Robust Bayesian Inference

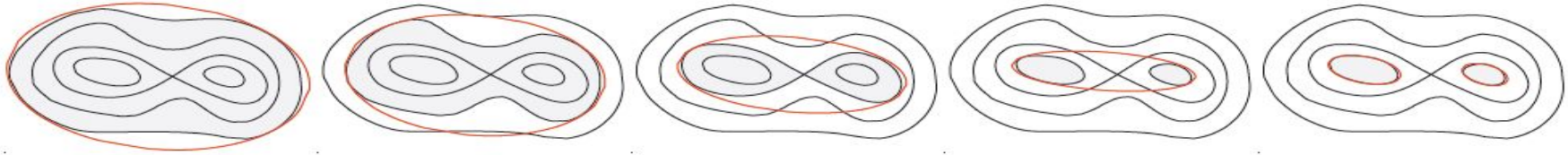






- Multiple peaks in the posterior identified and isolated

- iso-likelihood contours approximated by cov matrix of active points



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Glossary & Overview

You run the CosmoSIS command on a *parameter file*:

```
> cosmosis demos/demo1.ini
```

which describes various aspects of your analysis:

Modules:

- CosmoSIS calculations/likelihoods split into steps called *modules*.
- Run as a sequence, each taking inputs from previous modules and providing new outputs for later ones.
- Each module is given its own [section] in the parameter file:

```
[camb]
file = cosmosis-standard-library/boltzmann/camb/camb.so
mode=all
lmax=2500
feedback=2
```

Glossary & Overview

Pipeline: The sequence of modules to be run in your analysis for each likelihood

```
[pipeline]
modules = consistency camb
halofit
```

Values file: Another file with names and values or ranges of your parameters.

```
values = demos/values1.ini
```

```
[cosmological_parameters]
omega_m = 0.3
h0 = 0.6  0.7  0.8
```

Sampler: The code that chooses sets of parameters of which to evaluate the likelihood choosing them using MCMC or some other scheme.

```
[runtime]
sampler=test

[test]
save_dir=demo_output_1
fatal_errors=T
```

Test Sampler: The most trivial “sampler”, just runs one likelihood of a single set of parameters.

Glossary & Overview

Data Block: CosmoSIS mechanism for passing data between modules (more later)

Repositories: A way of storing, tracking, and sharing code. CosmoSIS comes with two “repos”, one for the main code and one for the modules (cosmosis-standard-library)

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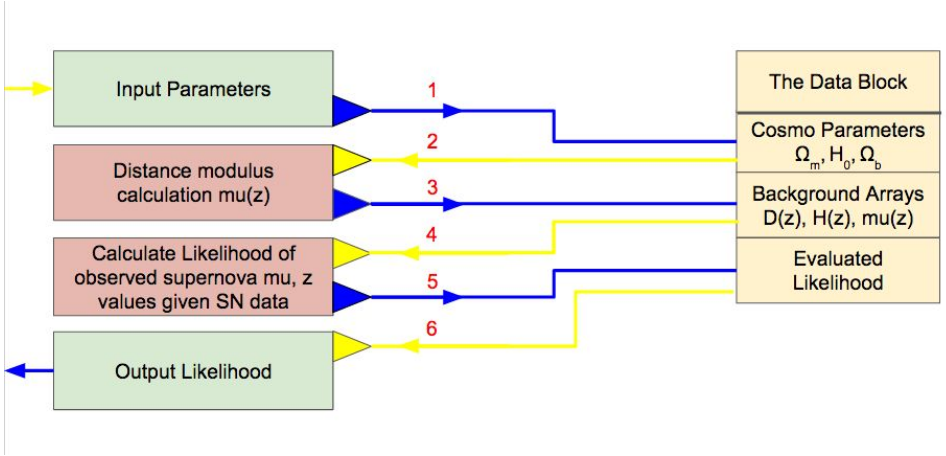
Running CosmoSIS: Demo 5

Last time we showed this diagram of a likelihood pipeline for supernova data.

Now we will look at demo 5 which shows how to run this in CosmoSIS.

The file demos/demo5.ini is the parameter file



Choosing a sampler

Setting parameters for this sampler

Choosing the output file

The values file

The module list

Expected likelihoods

```
[runtime]
; The emcee sampler, which uses the Goodman & Weare algorithm
sampler = emcee

[emcee]
; The emcee sampler uses the concept of walkers, a collection
; of live points.  Sampling is done along lines that connect
; pairs of walkers.  The number of walkers must be at least
; 2*nparam + 1, but in general more than that usually works
; better.
walkers = 64
; This many samples is overkill, just to make the plots
; look a lot nicer
samples = 400
; This is the interval at which convergence diagnostics
; are performed
nsteps = 100

[output]
filename = demo5.txt
format = text
verbosity= debug

[pipeline]
; We use two likelihoods, the JLA (for high redshift) and
; Riess 2011 to anchor H0, which is otherwise degenerate
; with the nuisance parameter M
modules = consistency camb jla riess11
values = demos/values5.ini
extra_output =
likelihoods = jla riess
quiet=T
debug=F
timing=F
```

Modules we asked for in the list above

```
[camb]
; For background-only data we do not need a full
; Boltzmann evaluation, just D(z), etc.
; Setting mode=background means we get this.
file = cosmosis-standard-library/boltzmann/camb/camb.so
mode=background
feedback=0

[jla]
; JLA needs quite a lot of parameters telling it where
; data files are ...
file = cosmosis-standard-library/supernovae/jla_v3/jla.so
data_dir = cosmosis-standard-library/supernovae/jla_v3/data
data_file = jla_lcparams.txt
scriptmcut = 10.0
mag_covmat_file = jla_v0_covmatrix.dat
stretch_covmat_file = jla_va_covmatrix.dat
colour_covmat_file = jla_vb_covmatrix.dat
mag_stretch_covmat_file = jla_v0a_covmatrix.dat
mag_colour_covmat_file = jla_v0b_covmatrix.dat
stretch_colour_covmat_file = jla_vab_covmatrix.dat

; The Riess 11 likelihood anchors H0 for us
[riess11]
file = cosmosis-standard-library/likelihood/riess11/riess11.py

; The consistency module translates between our chosen parameterization
; and any other that modules in the pipeline may want (e.g. camb)
[consistency]
file = cosmosis-standard-library/utility/consistency/consistency_interface.py
```

Files containing the module code

Other module parameters

Values File

Section (category) of parameters

Fixed parameter (single value only)

```
[cosmological_parameters]
omega_m  =  0.2    0.2935148566413599    0.4
h0  =  0.5    0.7380008925839199 9    1.0
w  =  -1.0
omega_b  =  0.04
omega_k  =  0.0

[supernova_params]
deltam  =  -10.0    0.040281808929275797    10.0
alpha  =  0.12    0.13675033800637484    0.16
beta  =  2.0    3.1029245604093223    10.0
m  =  -19.0
```

Varied parameter (min, start, max)

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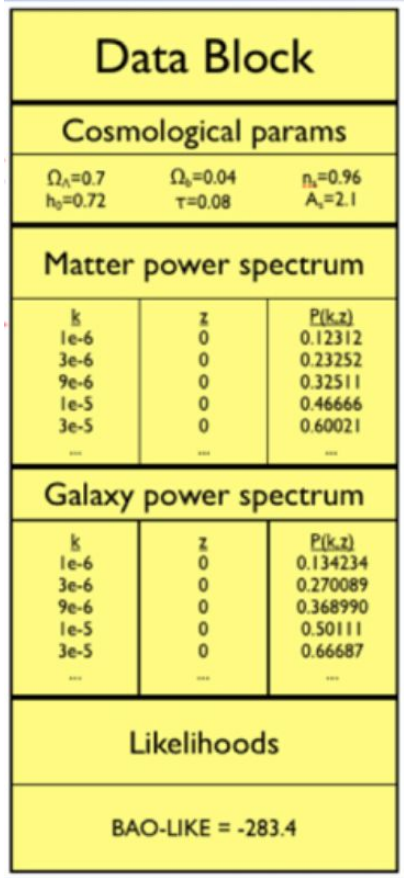
DataBlocks: A cross-language key-value store

Problem posed: how can different packages, written in a variety of languages, communicate with each other?

- Dark days before CosmoSiS: brute force approach was to use files and bash scripts to manage input/output. **This is very prone to error/bugs.**
- CosmoSIS has interface that accepts booleans, integers, doubles, strings, 1D arrays and 2D arrays. Implemented interface in C, C++, Python, Fortran.
- Section names avoid the problem of name clashing



DataBlocks: A cross-language key-value store

Get, Put and Replace data are the most common operations

```
block["section_name", "value_name"] = x
x = block["section_name", "value_name"]
```

Additional useful functions

```
block.has_section("section_name")
block.has_value("section_name", "value_name")
block.sections()
block.keys()
```

Check the wiki for instructions in all languages!

https://bitbucket.org/joezuntz/cosmosis/wiki/creating_modules

DataBlocks: Predefined sections

Go to the Wiki to check the names of predefined sections

Wiki

Clone wiki

cosmosis / default_sections

View History

All of these sections are predefined strings that you can use in CosmoSIS modules. They are typically used as the names of "sections" - groups of parameters and data collected together.

For an entry on this list called "name", in code you would use these pre-defined constants for the strings:

Python: cosmosis.names.name

C: NAME_SECTION

C++: NAME_SECTION

Fortran: name_section

Likelihoods

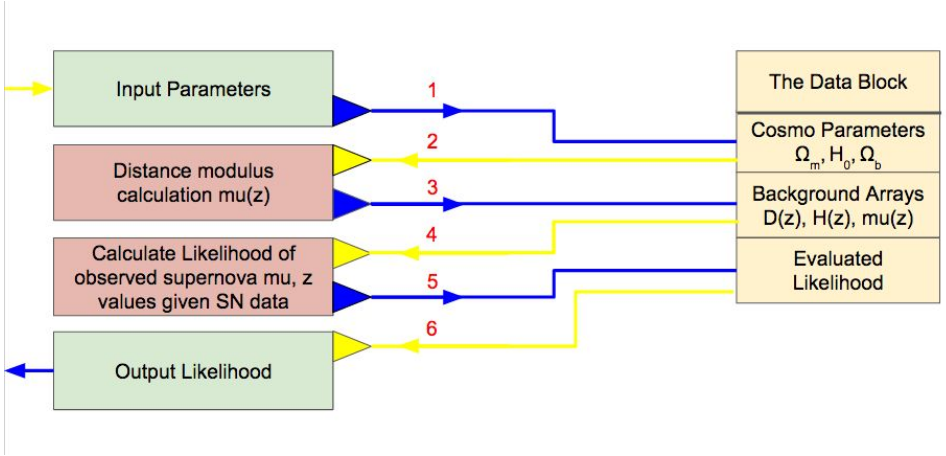
```
likelihoods
```

Input parameters

```
cosmological_parameters
halo_model_parameters
intrinsic_alignment_parameters
baryon_parameters
shear_calibration_parameters
number_density_params
```

Demo 5 should now be complete

Let’s look at the output...



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CosmoSIS Modules

- Adding new physics or likelihoods to CosmoSIS = modifying or creating **modules**

- Modules: **python files** or C/C++/Fortran code compiled into a **shared library**
  - Using the -shared compiler flag

- Have three special functions (incl. one optional):
  - `setup` - called once at the start; reads parameters from input param file
  - `execute` - called for each sample; reads inputs from *data block*
  - `cleanup` - called once at the end; frees memory/resources (optional)

Setup Functions

Input: “`options`”: DataBlock read from the input parameter file
Output: One value. Any python object, or in C/C++/Fortran a pointer to any object

Read any inputs you need from the parameter file, load any data files you need, etc.

```
def setup(options):
 X = options[options_section, "x"]
 # ...
 return {"setting1": X,"setting2": 3.14, "setting3": "potato"}
```

Execute Functions

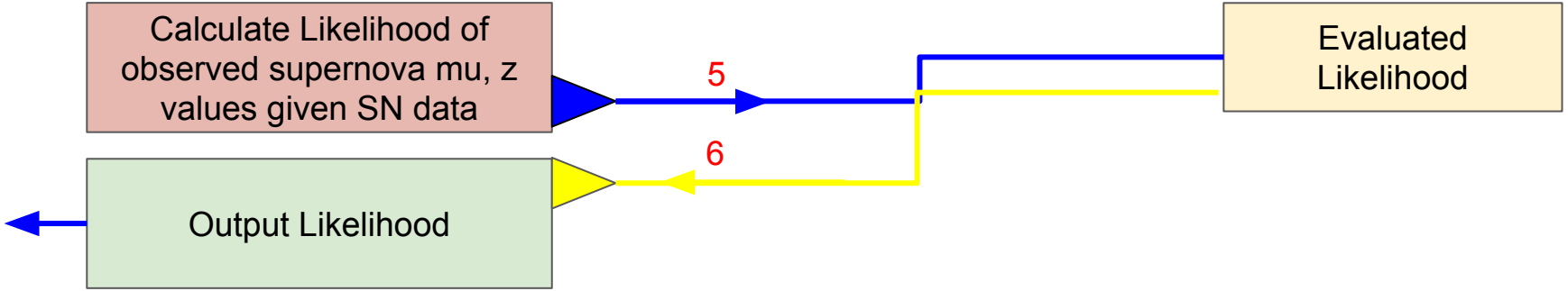
Inputs: `block`: a DataBlock with input params and outputs of previous module.
`config`: whatever was returned by the setup function.
Output: `status`: integer, 0 if all went well

Read any inputs you need from the parameter file, load any data files you need, etc.

```
def execute(block, config):
    X = config["setting1"]
    Omega = block["cosmological_parameters", "Omega_m"]
    # ...
    block["new_section", "new_output"] = 666.66
    return 0
```

Likelihood Modules

- Usually one of the last modules in a pipeline
- Same structure as any other module
- Add name to parameter file option `likelihoods = …` in param file
- Section `likelihoods` is search for `name_like` by the sampler
- e.g.
  - `block["likelihoods", "my_sn_like"] = -chi2/2.0  #python`
  - `c_datablock_put_double(block, "likelihoods", "my_sn_like", -chi2/2.0)  //C`



Likelihood Module Example

Example: WiggleZ BAO module

```python
def setup(options):
    #Load the data from the default location unless otherwise specified
    verbose = options.get_bool(option_section, "verbose", False)

    (...)

    #Return data for later
    return (z, Dv, weight_matrix, rs_fiducial, verbose)

def execute(block, config):
    #Unpack data loaded in depending on options
    z_data, dv_data, weight_matrix, rs_fiducial, verbose = config

    z = block[names.distances, "z"]
    da = block[names.distances, "D_A"]

    (...)

    like = -0.5*np.einsum('i,ij,j', delta, weight_matrix, delta)
    block[names.likelihoods, "wigglez_bao_like"] = like

    #Signal success
    return 0

def cleanup(config):
    pass
```

CosmoSIS Interface:

setup, execute, cleanup

DataBlock interface has two arguments

(1) Section Name
(2) Parameter Name

Using predefined names.likelihoods here

Setup & Execute Functions

Full details by language:
https://bitbucket.org/joezuntz/cosmosis/wiki/creating_modules

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Standard Library Modules

CAMB

CLASS

CosmoLike

SNANA

MGCAMB

MGCLASS

IsItGR

EFTCamb

Colossus

CosmoCalc

AstroPy

CosmoMC

Cosmolopy

Documentation of standard library:
https://bitbucket.org/joezuntz/cosmosis/wiki/default_modules

Modifying existing modules

Two parts:

- Modify physics/calculation itself
- Modify interface with CosmoSIS

Advanced example: modifying CAMB

$$w(z) = \sum_{i=0}^{4} w_i [\ln(1+z)]^i$$

- First we need to change CAMB (file: equations.f90)
- Then we need to change the interface between CAMB and the datablock (file: camb_interface.F90)

```
status = status + datablock_get_double_default(block, cosmo, "w", -1.0D0, w_lam)
status = status + datablock_get_double_default(block, cosmo, "wa",  0.0D0, wa_ppf)
```

- Update the ini file (see values1.ini associated with demo 1)

```
w = -1.0    ;equation of state of dark energy
wa = 0.0    ;equation of state of dark energy (redshift dependency)
```

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How to get credit?

How to Avoid the *Package too big for individual recognition* problem?

Example: The Astropy Problem - arXiv:1610.03159

- In the CosmoSIS module - add suggested citation in the yaml file.
- One possible solution: write code that performs very well (better than any other software in the market) so whenever people need the functionality your code provides, they will visit your github/website and credit your paper!
- Write code that people can incorporate in their pipeline easily with flexible options.

CosmoSiS is not a monolithic code - you can create a separate module that people can download from your github and incorporate in their pipeline!

Getting more information

Wiki

- Modules reference
- General reference

Issues page

- Existing issues
- Creating new issues

Any questions?