CASA’s simdata

- One command gets you
  - synthetic visibilities
  - a synthesized deconvolved image
  - analysis of differences between your input and the synthetic output.

- ALMA, (E)VLA, SMA, ATCA, you name it.

- All you need is a model of the sky
Outline

- **inputs**
  - array configuration
  - model image = “sky truth”
  - spatial and spectral parameters

- **outputs**
  - UV data
  - noninteractively cleaned image
  - difference from model and fidelity

- calculation of (noiseless) visibilities

- corruption of visibilities
  - thermal noise
  - atmospheric phase noise
  - X-pol and gain drift
Terminology

- colors
  - red = required
  - blue = optional
  - green = not yet fully implemented
- sm = Simulator tool
- simdata = task
Inputs: array configuration

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<th>optional</th>
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Header: obs name & coordinate system

optional
Inputs: array configuration

Header: obs name & coordinate system

Obs name has to be in data repository

Need to better document how users can add

optional

Supported coordinate systems:
- UTM
- ITRF earth-centered
- LOC local tangent plane offsets from COA
- GEO geodetic lat/lon

Delivered with CASA:
- ALMA, ACA, ALMA early science, ALMA
- CSV, EVLA, CARMA, SMA, ATNF, MeerKat
Set array configuration

Many are delivered with CASA, probably in /opt/casa/data/alma/simmos.
Set array configuration

On the Simulator wiki: Development planned for simdata to suggest a config given a synthesized beam size.

protoplanet
Set up model

First, we need a model of the sky. simdata can use a clean component list or an image (fits or CASA).

Next, you have to decide whether you want to use the World Coordinate System in the image or not.

```
CASA <46>: inp
---------- inp()
# simdata :: mosaic simulation task:
modelimage = 'diskmodel.im'  # input image name
ignorecoord = False         # scale model coordinates to output parameters
inbright = 'unchanged'      # set peak surface brightness in Jy/pixel or "unchanged"
complist = ''               # componentlist table to observe
antennalist = '/Applications/CASA.app/Contents/data/alma/simmos/alma.out20.cfg'  # antenna position file
checkinputs = 'no'          # graphically verify parameters [yes|no|only]

startfreq = '668.0GHz'      # frequency of first channel
chanwidth = '8.0GHz'        # channel width
nchan = 1                   # number of channels
direction = 'J2000 18h00m00.0s -45d59m59.6s'  # mosaic center, or list of pointings
pointinspacings = '0.5arcsec'  # spacing in between beams in mosaic
                           # btw. pointings and edge, relative to pointings spacing
outcell = '1cell'           # output cell/pixel size
outimage = '0.125arcsec'    # output image size in pixels (x,y)
maxnumiter = 100            # maximum number of iterations
threshold = '0.0mJy'        # flux level (+units) to stop cleaning
psfmode = 'clark'           # method of PSF calculation to use during minor cycles
weighting = 'natural'       # weighting to apply to visibilities
uv taper = False            # apply additional uv tapering of visibilities.
stokes = 'I'                # Stokes params to image
noise_thermal = False       # add thermal noise
fidelity = False            # Calculate fidelity images
display = False             # Plot simulation result images, figures
verbose = False             # If true the taskname must be started using simdata(...)
```

CASA <47>: 
Set up model

If you're happy with your input WCS, or you can edit it to your satisfaction, leave ignorecoord=False. Yes, it's a double negative.

If you just want to set the flux brightness scale, use “inbright”
Imhead shows what you have:

CASA <41> imhead(imagename=“diskmodel.im”) (default output is to logger)

This image already has 4 axes – RA, Dec, Stokes, and Frequency. In fact, we only need the two spatial axes, because simdata will add the others for you.
What if I don’t want my WCS?

If you don’t want to use the World Coordinate System, or you don’t have one, set ignorecoord=True

Simdata will set your model image
- spatial pixel to “cell”
- spectral channel width to “chanwidth”
- spectral bandpass starting frequency to “startfreq”
- image centered on “direction”
What if I don’t want my WCS?

Remember, you get $\text{project.$modelimage.coord}$ with simdata’s idea of a CoordinateSystem

You can start a second simulation with that as modelimage.
Set up observation

“direction” can be a list, if you know what pointings you want, or a center point, in which case simdata will try to fill your area with a mosaic of pointings.

* Source – cal – source sequence is possible in the tool only at the moment
Set up observation

Mosaic positions will be in a hex pattern separated by "pointingspacing", with a border around the edge of "relmargin" pointing spacings
Set up observation

Go ahead and set the size and pixel size of your output image even if you only want to create a measurement set. Simdata will try to build you a mosaic based on the sky you want out, not the sky you put in.

```casa
CASA <46>: inp
------------> inp()
# simdata :: mosaic simulation task:
modelimage  = 'diskmodel.im'  # input image name
ignorecoord = False          # scale model coordinates to output parameters
inbright    = 'unchanged'    # set peak surface brightness in Jy/pixel or "unchanged"
complist    = ''             # componentlist table to observe
antennalist = '/Applications/CASA.app/Contents/data/alma/simmos/alma.out20.cfg' # antenna position file
checkinputs = 'no'           # graphically verify parameters [yes|no|only]
project     = 'psim'          # root for output files
refdate     = '"2012/06/21/03:25:00' # center time/date of observation *see help
totaltime   = '1200s'        # total time of observation
integration = '10s'          # integration (sampling) time
startfreq   = '668.0GHz'     # frequency of first channel
chanwidth   = '8.0GHz'       # channel width
nchan       = 1              # number of channels
direction   = 'J2000 18h00m00.03s -45d59m59.6s' # mosaic center, or list of pointings
pointingspacing = '0.5arcsec' # spacing in between beams in mosaic
relmargin   = 1.0            # space btw. pointings and edge, relative to pointingspacing
cell       = '0.004arcsec'   # output cell/pixel size
imsizes     = [192, 192]    # output image size in pixels (x,y)
niter       = 100            # maximum number of iterations
threshold   = '0.0mJy'       # flux level (+units) to stop cleaning
async       = False          # If true the taskname must be started using simdata(...)
```
Set up spectral information. If you are interested in a 2d (continuum) simulation, set chanwidth to e.g. 4GHz, and nchan=1

* Multiple SPW: some aspects, like corruption, can be handled at the tool level. Simdata task can do one.
Set up what you want to calculate

Parameters that control imaging – this just calls clean(). If you don’t want to deconvolve at all, set psfmode="none"
simdata doesn’t try very hard with clean, but it does tell you what inputs it used.
Set up what you want to calculate

Display=True to get the nice graphical output

Fidelity=True to calculate a fidelity image (a measure of how well your synthesis image represents the sky)
Run it already!
In one command, CASA generates

- uv data (with thermal noise if desired)
- a dirty and cleaned image.
- a diagnostic window including
  - your input
  - the simulated image
  - the difference
  - uv coverage
  - and dirty beam or PSF
What else do we get?

$\text{project.$modelimagecoord} = \text{image with CoordinateSystem} – \text{If it’s a cube, also look at $\text{project.$modelimageflat}}$

$\text{project.convolved} = \text{input convolved with output synthesized beam}$

$\text{project.ms} = \text{MeasurementSet}$

$\text{project.clean.image} = \text{output synthesized image again, if a cube, also look for $\text{project.cleanflat}}$

$\text{project.clean.psf}$

$\text{project.diff.im, $\text{project.fidelity.im} = \text{difference and fidelity}}$
What is this “fidelity” of which you speak?

http://www.alma.nrao.edu/memos/
These deal with simulation: 488, 398, 387, 386

\[\text{fidelity} = \frac{\text{input}}{\text{abs}(\text{input} - \text{output})} = \frac{\text{input}}{\text{difference}}\]

\[\text{fidelity} = \frac{\text{input}}{\text{max}(\text{difference}, 0.7 * \text{rms}(\text{difference}))}\]
What if I don’t like to wait?

To check that you have the sizes and pointings set the way you want them, without waiting for the entire calculation, set checkinputs="only".
checkinputs
I want noise!

In simdata, we have thermal noise (rest in sm tool)
* Interface likely to change slightly this week

```plaintext
# simdata :: mosaic simulation task:
modelimage = 'diskmodel.im'  # input image name
ignorecoord = True  # scale model coordinates to output parameters
inbright = '7.2e-7'  # set peak surface brightness in Jy/pixel or "unchanged"
complist = ','  # componentlist table to observe
antennalist = '/Applications/CASA.app/Contents/data/alma/simmos/alma.out20.cfg'  # antenna
checkinputs = 'only'  # graphically verify parameters [yes|no|only]
project = 'psim'  # root for output files
refdate = '2012/06/21/03:25:00'  # center time/date of observation *see help
totalltime = '1200s'  # total time of observation
integration = '10s'  # integration (sampling) time
startfreq = '668.0GHz'  # frequency of first channel
chanwidth = '8.0GHz'  # channel width
nchan = 1  # number of channels
direction = 'J2000 18h00m00.0s -45d59m59.6s'  # mosaic center, or list of pointings
pointingspacing = '0.5arcsec'  # spacing in between beams in mosaic
remlim = 1.0  # space btw. pointings and edge, relative to pointingspacing
cell = '0.004arcsec'  # output cell/pixel size
imsize = [192, 192]  # output image size in pixels (x,y)

uv taper = False  # apply additional uv tapering of visibilities.
stokes = 'I'  # Stokes params to image
noise thermal = True  # add thermal noise
t_amb = 265.0  # ambient temperature
tau0 = 0.1  # zenith opacity

fidelity = False  # Calculate fidelity images
display = False  # Plot simulation result images, figures
verbose = False
async = False  # If true the taskname must be started using simdata(...)```
Thermal noise

System temperature referenced above the atmosphere – usually the source signal \( T_A^* \) is neglected

\[
T_{sys} = \eta_{spill} T_A^* + T_{CMB} + \eta_{spill} T_{atm} (e^\tau - 1) + (1 - \eta_{spill}) T_{amb} e^\tau + T_{RX} e^\tau
\]

\[
\tau = \tau(\nu, \text{airmass})
\]

Random noise is added to the real and imaginary parts of the visibilities according to the average of the airmasses seen by the two antennas making up each given baseline.

The noise is actually applied in Janskies with the following conversion:

\[
F_\nu = \frac{4\sqrt{2}k10^{-23}}{\eta_{ant}\eta_{correl}\pi d_1 d_2 \sqrt{2\Delta v\Delta t}} T_{sys}
\]

A new noisy MS is created, and optionally a cal table containing the added noise
Thermal noise
Atmospheric phase delay

From Bojan Nikolic’s presentation of real path fluctuation measured at the SMA, and the calculated path (blue) from WVR data.
Atmospheric phase delay

Stirling memo 517: convective simulations reveal PWV fluctuations concentrated in a layer, with approximately fractal structure in the horizontal plane:
Atmospheric phase delay

Bojan Nikolic memo 588
approximate real hydro simulation with a static phase screen, blown over the array.

Figure 2. A one-eighth subsection of the turbulent phase screen used in the simulation of empirically determining the correlation between temperature brightness and phase fluctuations. The scale is in arbitrary units, as the screen is later re-scaled so that the fluctuation on a 300 m baseline is 200 μm.

my implementation in CASA: fractional Brownian motion or generalized 1/f noise
- a statistically good representation of many stochastic natural processes
- this phase screen approximation has been verified with on-site measurements e.g. Ishizaki memo 529.
- Bojan’s work has quantified the errors from using a 2-d screen v. a 3d screen (which can take into account the different WVR and science receiver beams)
- 2d should be sufficient for current implementation in CASA, enhancement possible

Generated in Fourier space, with X a random variable in [0,1],
i_th phase = 2πX, i_th amplitude = X i^β/2
Atmospheric phase delay
What is generated is a PWV screen, then Pardo’s ATM library is used to calculate phase...
Atmospheric phase delay

Actual cal table generated, for 2 antennas that lie close to the wind direction:
Atmospheric phase delay

Applied to a MS:
Atmospheric phase delay
Atmospheric phase delay

Today, use tool. Hope to interface to simdata task for 3.0 release

```casa
CASA> sm.openfromms("my.ms")
CASA> sm.settrop(pwv=1.)
CASA> sm.corrupt()
CASA> sm.done()
```
Corruption summary

Thermal noise: sm.setnoise2
- user sets $T_{RX}$, $T_{CMB}$, $T_{atmos}$, and efficiencies
- $\tau(\nu)$ calculated using ATM or user specifies a value
- $\tau$ and atmospheric $T_{b}$ could be calculated more self-consistently, from user-specified altitude, PWV, etc

Thermal noise: simdata
- user sets $T_{atmos}$ and $\tau$, simdata looks up sensible atmosphere for the site, and looks up receiver specs for the given observatory (could do with a bit more flexibility and more complete site info)

Atmospheric phase screen: sm.settrop
- individual (uncorrelated) fluctuations for each antenna
- 2d screen blows across the array

Cross-polarization: sm.setleakage – only constant at the moment

Gain fluctuation: sm.setgain – constant or fractional brownian motion fluctuations

Bandpass and pointing errors – BP soon, pointing = Sanjay.

Variable feed angles on different antennas – Spring 2010
ALMA

Images showing various ALMA observations, including SNR ALMA 2.941.1-0.3 flat, SNR ALMA 2. clean flat, and SNR ALMA 2. differ image. Each image highlights different parameters such as minimum, maximum, and RMS values. Additionally, a map showing J2000 Right Ascension is included for reference.