BAYESIAN ANALYSIS TOOLKIT: 1.0 AND BEYOND

Frederik.Beaujean@lmu.de
Excellence cluster universe, LMU Munich

CHEP 2015, Okinawa

BAT men: F.B., A. Caldwell, D. Greenwald, D. Kollár, K. Kröninger, O. Schulz, S. Kluth

QUESTION

Given data from LHC, what are likely values of masses, cross sections…?
Limits including systematic uncertainties?

Bayes' theorem

Learning rule

$$\boxed{P(\theta|D,M) \propto P(D|\theta,M)P_0(\theta|M)}$$

posterior $\propto$ likelihood $\times$ prior

Applying Bayes' theorem

Integration

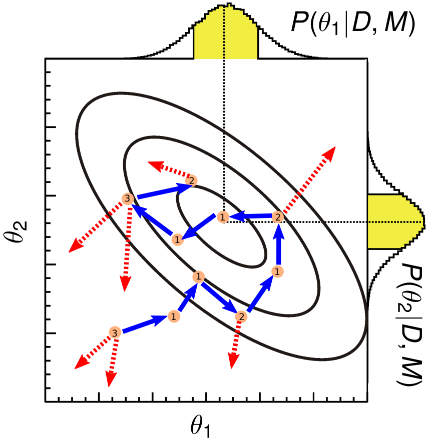
- marginalization $P(\theta_i|D, M) = \int \prod_{j \neq i} \mathrm{d}\theta_j \, P(\boldsymbol{\theta}|D, M)$
- evidence $P(D|M) = \int \mathrm{d}\boldsymbol{\theta} \, P(D|\boldsymbol{\theta}, M) P_0(\boldsymbol{\theta}|M)$
- quadrature $\rightarrow$ curse of dimensionality

Applying Bayes' theorem

Integration

- marginalization $P(\theta_i|D, M) = \int \prod_{j \neq i} \mathrm{d}\theta_j \, P(\boldsymbol{\theta}|D, M)$
- evidence $P(D|M) = \int \mathrm{d}\boldsymbol{\theta} \, P(D|\boldsymbol{\theta}, M) P_0(\boldsymbol{\theta}|M)$
- quadrature $\rightarrow$ curse of dimensionality

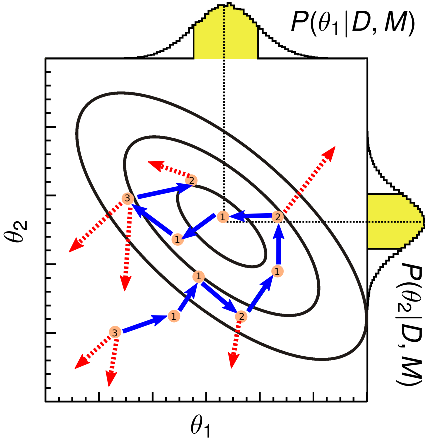
$\Rightarrow$ need samples from posterior



METROPOLIS HASTINGS ALGORITHM

one sample per step

1. propose move
2. accept or stay



Metropolis Hastings algorithm

one sample per step

1. propose move
2. accept or stay

- marginals
- sample near mode $\Rightarrow$ seed for optimization
- uncertainty propagation $f(\boldsymbol{\theta}) \rightarrow P(f|D, M)$

- home page http://mpp.mpg.de/bat
- fork me on https://github.com/bat/bat

MOTIVATION

- reinventing the wheel time waster, error prone
- C++ toolkit to supply algorithms/models $\Rightarrow$ user can focus on problem

Bayesian Analysis Toolkit

BAYESIAN ANALYSIS TOOLKIT

- home page http://mpp.mpg.de/bat
- fork me on https://github.com/bat/bat

Features

- implemented: MCMC (multithreaded), simulated annealing . . .
- depends on ROOT: I/O, plots, optimization (Minuit) . . .
- optional: roostats, CUBA (integration)
- docs, tutorials, examples . . . on web page

COMPONENTS

$$\boxed{P(\boldsymbol{\theta}|D, M) \propto P(D|\boldsymbol{\theta}, M)P_0(\boldsymbol{\theta}|M)}$$

USER DEFINED

- create model
- read data

Components

$$\boxed{P(\theta|D, M) \propto P(D|\theta, M) P_0(\theta|M)}$$

User defined

- create model
- read data

Define MyModel : BCModel

- `AddParameter("mu", 0, 1)`
- `LogLikelihood()`
- `LogAPrioriProbability()`

Components

$$\boxed{P(\theta|D,M) \propto P(D|\theta,M)P_0(\theta|M)}$$

User defined

- create model
- read data

Common tools

- `Normalize()`
- `FindMode()`
- `MarginalizeAll()`
- `PrintAllMarginalized()`
- `PrintKnowledgeUpdatePlots()`

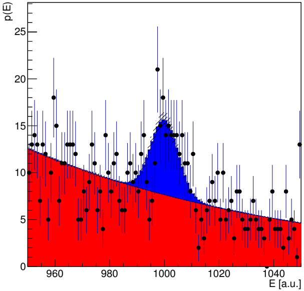
Define MyModel : BCModel

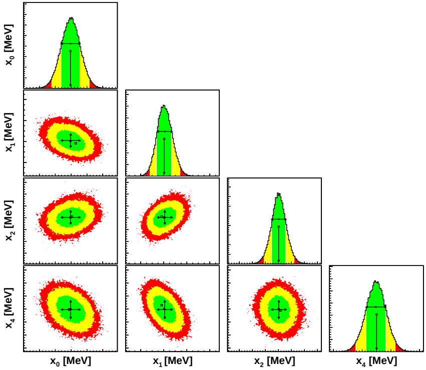
- `AddParameter("mu", 0, 1)`
- `LogLikelihood()`
- `LogAPrioriProbability()`

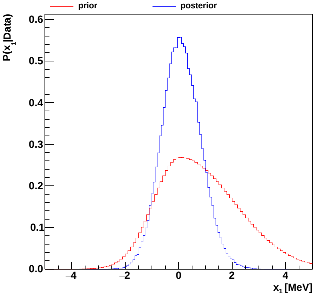
Predefined model

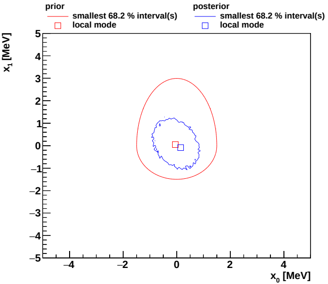
template fit: signal + bkg

```
// define the model
BCMTF m("SingleChannelMTF");
m.AddChannel("channel1");
m.SetData("channel1", hist_data);
m.AddProcess("background", 200., 400.);
m.SetTemplate("channel1", "background",
      hist_background, 1.0);
m.SetPriorGauss("background", 300., 10.);
m.AddProcess("signal", 0., 200.);
m.SetTemplate("channel1", "signal", hist_signal, 1.0);
m.SetPriorConstant("signal");
```

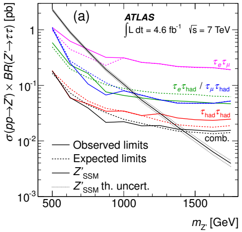






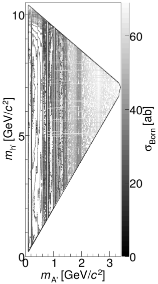



```
// run MCMC, find mode, then plot
m.MarginalizeAll();
m.FindMode(m.GetBestFitParameters());
m.PrintKnowledgeUpdatePlots("upd.pdf");
m.PrintCorrelationPlot("corr.pdf");
```



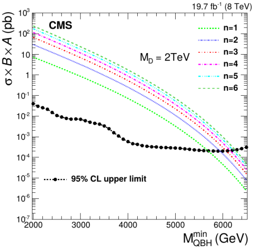
ATLAS: Z'

Phys. Lett. B 719 (2013)



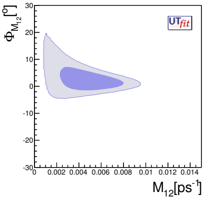
Belle: dark photon

arXiv:1502.00084



CMS: quantum black hole

arXiv:1501.04198v2



UTFIT: D meson mixing

arXiv:1402.1664

110 citations@inspire, ∼ 100 downloads of v0.9.4.1 since Jan 20, 2015

HISTORY

- first release 2008
- subversion
- one of two main developers left physics

HISTORY

- first release 2008
- subversion
- one of two main developers left physics

PRESENT

1. better code with git: distributed, code review

History

- first release 2008
- subversion
- one of two main developers left physics

Present

1. better code with git: distributed, code review
2. benefit from github: discuss issues, fork, pull requests…

Lessons in software engineering

History

- first release 2008
- subversion
- one of two main developers left physics

Present

1. better code with git: distributed, code review
2. benefit from github: discuss issues, fork, pull requests...
3. write unit tests: refactor code, add features w/o worrying, automatic tests on different platforms

⇒time investments pay off

BAT 1.0

Improvements under development

- ease of use: streamline option setting, building ...
- factorized priors $P(\boldsymbol{\theta}|M) = \prod_i P(\theta_i|M)$

  $\Rightarrow$ community extensible
- sharing samples as ROOT files (even w/o the model)
  $\Rightarrow$ uncertainty propagation, replotting
- multivariate proposal $\Rightarrow$ big speed-up in high dimensions
- evidence from MCMC arXiv:1410.7149

$\Rightarrow$ release in summer 2015

Wishlist for the future

- threads + MPI for tough problems $\Rightarrow$rewrite
- interface to script languages: python, mathematica, R . . .
- sampling algorithms: MCMC, Hamiltonian MC, nested sampling, variational Bayes + importance sampling . . .

Summary

1. Bayes: random numbers
2. BAT well established
3. more powerful sampling algorithms in BAT 2.0