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# Evaluating probabilistic programming languages for simulating quantum correlations

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**Protocol status:** In development

**We are still developing and optimizing this protocol**

**Created:** November 01, 2018

**Last Modified:** November 01, 2018

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## Set up of environment required for PyMC3, Pyro & Turing.jl (MAC OS X)

1

Navigate to the folder in which you would like to conduct the experimentation.

Then open your terminal application:

### Software

**Terminal**

NAME

Mac OS X

OS

Apple

DEVELOPER

### Command

Create a virtual environment to house the required packages.

```
virtualenv env
```

### Command

**Activate the environment**

```
source env/bin/activate
```

Then create a new file entitled "pymc3-main.py", and populate it with the following text:



## Command

```
from numpy import zeros, array, fliplr, sum
from itertools import product
import pymc3 as pm
import time

def get_vertex(a, b, x, y):
    return ((x*8)+(y*4))+(b+(a*2))

def get_hyperedges(H, n):
    l = []
    for idx, e in enumerate(H):
        if n in e:
            l.append(idx)
    return l

def foulis_randall_product():
    fr_edges = []
    H = [ [[0, 0], [1, 0]], [[0, 1], [1, 1]],
          [[0, 0], [1, 0]], [[0, 1], [1, 1]] ]
    for edge_a in H[0]:
        for edge_b in H[1]:
            fr_edge = []
            for vertex_a in edge_a:
                for vertex_b in edge_b:
                    fr_edge.append([
                        vertex_a[0], vertex_b[0],
                        vertex_a[1], vertex_b[1]])
            fr_edges.append(fr_edge)
    for mc in range(0,2):
        mc_i = abs(1-mc)
        for edge in H[mc]:
            for j in range(0,2):
                fr_edge = []
                for i in range(0, len(edge)):
                    edge_b = H[mc_i][i]
                    vertex_a = edge[abs(i-j)]
                    vertex_b = edge_b[0]
                    vertex_c = edge_b[1]
                    vertices_a = [
                        vertex_a[0], vertex_b[0],
                        vertex_a[1], vertex_b[1]]
```

```
vertices_b = [
    vertex_a[0], vertex_c[0],
    vertex_a[1], vertex_c[1]]
fr_edge.append([
    vertices_a[mc], vertices_a[mc_i],
    vertices_a[mc+2], vertices_a[mc_i+2]]
)
fr_edge.append([
    vertices_b[mc], vertices_b[mc_i],
    vertices_b[mc+2], vertices_b[mc_i+2]])
fr_edges.append(fr_edge)
return fr_edges

def generate_global_distribution(constraints,N):
    hyperedges = foulis_randall_product()
    hyperedges_tallies = zeros(12)
    global_distribution = zeros(16)
    while sum(global_distribution) < N:
        with pm.Model():
            pm.Uniform('C',0.0,1.0)
            pm.Bernoulli('A',0.5)
            pm.Bernoulli('B',0.5)
            pm.Bernoulli('X',0.5)
            pm.Bernoulli('Y',0.5)
            S = pm.sample(N,tune=0, step=pm.Metropolis())
            c = S.get_values('C')
            a = S.get_values('A')
            b = S.get_values('B')
            x = S.get_values('X')
            y = S.get_values('Y')
        for i in range(0, N):
            if (c[i] < constraints[x[i]][y[i]][a[i],b[i]]):
                for edge in get_hyperedges(hyperedges,
                    [a[i], b[i], x[i], y[i]]):
                    hyperedges_tallies[edge] += 1
                global_distribution[
                    get_vertex(a[i], b[i], x[i], y[i])] += 1
    z = [0,1]
    for a, b, x, y in product(z,z,z,z):
        summed_tally = (sum(hyperedges_tallies[e]
            for e in get_hyperedges(hyperedges, [a, b, x, y])))
        global_distribution[get_vertex(a, b, x, y)] /= summed_tally
    global_distribution *= 3
    return global_distribution

# execution
```

```
def accuracy_time(N):
    constraints = [[ array([[0.5, 0], [0., 0.5]]), array([[0.5, 0],
[0., 0.5]]) ],[ array([[0.5, 0], [0., 0.5]]), array([[0, 0.5], [0.5,
0.]]) ]]
    start = time.time()
    Q = generate_global_distribution(constraints,N)
    end = time.time()
    p = Q
    A11 = (2 * (p[0] + p[1])) - 1
    A12 = (2 * (p[4] + p[5])) - 1
    A21 = (2 * (p[8] + p[9])) - 1
    A22 = (2 * (p[12] + p[13])) - 1
    B11 = (2 * (p[0] + p[2])) - 1
    B12 = (2 * (p[8] + p[10])) - 1
    B21 = (2 * (p[4] + p[6])) - 1
    B22 = (2 * (p[12] + p[14])) - 1
    delta = (abs(A11 - A12) + abs(A21 - A22) + abs(B11 - B21) +
abs(B12 - B22))/2
    A11B11 = (p[0] + p[3]) - (p[1] + p[2])
    A12B12 = (p[4] + p[7]) - (p[5] + p[6])
    A21B21 = (p[8] + p[11]) - (p[9] + p[10])
    A22B22 = (p[12] + p[15]) - (p[13] + p[14])
    print("Time:")
    print(end - start)

    print("Normalization in contexts: ", [p[0]+p[1]+p[6]+p[7]])
    print("Normalization in contexts: ", [p[2]+p[3]+p[4]+p[5]])
    print("Normalization in contexts: ", [p[8]+p[9]+p[14]+p[15]])
    print("Normalization in contexts: ", [p[10]+p[11]+p[12]+p[13]])

    print("delta: ", delta)
    print("Potential violations: ")
    print(abs(A11B11 + A12B12 + A21B21 - A22B22), 2 * (1 + delta))
    print(abs(A11B11 + A12B12 - A21B21 + A22B22), 2 * (1 + delta))
    print(abs(A11B11 - A12B12 + A21B21 + A22B22), 2 * (1 + delta))
    print(abs(-A11B11 + A12B12 + A21B21 + A22B22), 2 * (1 + delta))

accuracy_time(1000)
accuracy_time(2000)
accuracy_time(3000)
accuracy_time(4000)
accuracy_time(5000)
accuracy_time(6000)
accuracy_time(7000)
accuracy_time(8000)
```



```
accuracy_time(8000)
accuracy_time(9000)
accuracy_time(10000)
accuracy_time(15000)
accuracy_time(20000)
accuracy_time(25000)
accuracy_time(30000)
accuracy_time(35000)
accuracy_time(40000)
accuracy_time(45000)
accuracy_time(50000)
accuracy_time(55000)
accuracy_time(60000)
accuracy_time(65000)
accuracy_time(70000)
accuracy_time(75000)
accuracy_time(80000)
accuracy_time(85000)
accuracy_time(90000)
accuracy_time(95000)
accuracy_time(100000)
```

Then create a new file entitled "pyro-main.py", and populate it with the following text:





## Command

```
from pyro import sample
import torch
from numpy import zeros, array, fliplr, sum
from functools import reduce
from itertools import product
from pyro.distributions import Bernoulli, Uniform
import pprint
import sys
import time

def foulis_randall_product():
    fr_edges = []
    H = [ [[0,0],[1,0]],[[0,1],[1,1]]], [[0,0],[1,0]],[[0,1],
                                                                 [1,1]] ]

    for edge_a in H[0]:
        for edge_b in H[1]:
            fr_edge = []
            for vertex_a in edge_a:
                for vertex_b in edge_b:
                    fr_edge.append([ vertex_a[0], vertex_b[0],
vertex_a[1], vertex_b[1]])
            fr_edges.append(fr_edge)
    for mc in range(0,2):
        mc_i = abs(1-mc)
        for edge in H[mc]:
            for j in range(0,2):
                fr_edge = []
                for i in range(0, len(edge)):
                    edge_b = H[mc_i][i]
                    vertex_a = edge[abs(i-j)]
                    vertex_b = edge_b[0]
                    vertex_c = edge_b[1]
                    vertices_a = [
                        vertex_a[0], vertex_b[0], vertex_a[1],
vertex_b[1]
                    ]
                    vertices_b = [
                        vertex_a[0], vertex_c[0], vertex_a[1],
vertex_c[1]
                    ]
                    fr_edge.append([
                        vertices_a[mc], vertices_a[mc+1],
```

```
vertices_a[mc+2], vertices_a[mc_i+2]
        ])
        fr_edge.append([
            vertices_b[mc], vertices_b[mc_i],
vertices_b[mc+2], vertices_b[mc_i+2]
        ])
        fr_edges.append(fr_edge)
    return fr_edges

def variable(v):
    return torch.autograd.Variable(torch.Tensor([v]))

def get_vertex(a, b, x, y):
    return ((x*8)+(y*4))+(b+(a*2))

def get_hyperedges(H, n):
    l = []
    for idx, e in enumerate(H):
        if n in e:
            l.append(idx)
    return l

def generate_global_distribution(constraints,N):
    hyperedges = foulis_randall_product()
    hyperedges_tallies = zeros(12)
    global_distribution = zeros(16)
    while sum(global_distribution) < N:
        a = int(sample('A', Bernoulli(variable(0.5))))
        b = int(sample('B', Bernoulli(variable(0.5))))
        x = int(sample('X', Bernoulli(variable(0.5))))
        y = int(sample('Y', Bernoulli(variable(0.5))))
        value = float(sample('C', Uniform(variable(0.0),
variable(1.0))))
        if (value < constraints[x][y][a,b]):
            for edge in get_hyperedges(hyperedges, [a, b, x, y]):
                hyperedges_tallies[edge] += 1
            global_distribution[get_vertex(a, b, x, y)] += 1
    for a, b, x, y in product(range(2), range(2), range(2), range(2)):
        summed_tally = (sum(hyperedges_tallies[e] for e in
get_hyperedges(hyperedges, [a, b, x, y])))
        global_distribution[get_vertex(a, b, x, y)] /= summed_tally
    global_distribution *= 3
    return global_distribution
```

```
def accuracy_time(N):
    print("Iterations %s" % (N))
    constraints = [[ array([[0.5, 0], [0., 0.5]]), array([[0.5, 0],
[0., 0.5]]) ],[ array([[0.5, 0], [0., 0.5]]), array([[0, 0.5], [0.5,
0.]]) ]]
    start = time.time()
    Q = generate_global_distribution(constraints,N)
    end = time.time()
    p = Q
    A11 = (2 * (p[0] + p[1])) - 1
    A12 = (2 * (p[4] + p[5])) - 1
    A21 = (2 * (p[8] + p[9])) - 1
    A22 = (2 * (p[12] + p[13])) - 1
    B11 = (2 * (p[0] + p[2])) - 1
    B12 = (2 * (p[8] + p[10])) - 1
    B21 = (2 * (p[4] + p[6])) - 1
    B22 = (2 * (p[12] + p[14])) - 1
    delta = (abs(A11 - A12) + abs(A21 - A22) + abs(B11 - B21) +
abs(B12 - B22))/2
    A11B11 = (p[0] + p[3]) - (p[1] + p[2])
    A12B12 = (p[4] + p[7]) - (p[5] + p[6])
    A21B21 = (p[8] + p[11]) - (p[9] + p[10])
    A22B22 = (p[12] + p[15]) - (p[13] + p[14])
    print("Time:")
    print(end - start)

    print("Normalization in contexts: ", [p[0]+p[1]+p[6]+p[7]])
    print("Normalization in contexts: ", [p[2]+p[3]+p[4]+p[5]])
    print("Normalization in contexts: ", [p[8]+p[9]+p[14]+p[15]])
    print("Normalization in contexts: ", [p[10]+p[11]+p[12]+p[13]])

    print("delta: ", delta)
    print("Potential violations: ")
    print(abs(A11B11 + A12B12 + A21B21 - A22B22), 2 * (1 + delta))
    print(abs(A11B11 + A12B12 - A21B21 + A22B22), 2 * (1 + delta))
    print(abs(A11B11 - A12B12 + A21B21 + A22B22), 2 * (1 + delta))
    print(abs(-A11B11 + A12B12 + A21B21 + A22B22), 2 * (1 + delta))

accuracy_time(1000)
accuracy_time(2000)
```



```
accuracy_time(2000)
accuracy_time(3000)
accuracy_time(4000)
accuracy_time(5000)
accuracy_time(6000)
accuracy_time(7000)
accuracy_time(8000)
accuracy_time(9000)
accuracy_time(10000)
accuracy_time(15000)
accuracy_time(20000)
accuracy_time(25000)
accuracy_time(30000)
accuracy_time(35000)
accuracy_time(40000)
accuracy_time(45000)
accuracy_time(50000)
accuracy_time(55000)
accuracy_time(60000)
accuracy_time(65000)
accuracy_time(70000)
accuracy_time(75000)
accuracy_time(80000)
accuracy_time(85000)
accuracy_time(90000)
accuracy_time(95000)
accuracy_time(100000)
```

Then create a new file entitled "turing-main.jl", and populate it with the following text:



## Command

```
using Turing
using Distributions
```

```
function foulis_randall_product()
    fr_edges = Array{Array{Array{Float64}}}()
    H = [ [[0.0,0.0],[1.0,0.0]],[[0.0,1.0],[1.0,1.0]]],
          [[0.0,0.0],[1.0,0.0]],[[0.0,1.0],
[1.0,1.0]]]
    for i = 1:size(H[1])[1]
        for j = 1:size(H[2])[1]
            fr_edge = Array{Array{Float64}}()
            for k = 1:size(H[1][i])[1]
                for l = 1:size(H[1][j])[1]
                    append!( fr_edge,
                        [[ H[1][i][k][1]
, H[2][j][l][1] ],
                        [ H[1][i][k][2]
, H[2][j][l][2] ] ] )
                end
            end
            append!( fr_edges, [ fr_edge ] )
        end
    end
    for mc = 1:2
        mc_i = abs(3-mc)
        for k = 1:size(H[mc])[1]
            for j = 1:2
                fr_edge = Array{Array{Float64}}()
                for i = 1:size(H[mc][k])[1]
                    edge_b = H[mc_i][i]
                    vertex_a = H[mc][k][abs(i-
j)+1]
                    vertex_b = edge_b[1]
                    vertex_c = edge_b[2]
                    vertices_a = [ vertex_a[1], vertex_b[1],
                                vertex_a[2],
                                vertex_b[2]]
                    vertices_b = [ vertex_a[1], vertex_c[1],
                                vertex_a[2],
                                vertex_c[2]]
                    this edge b = Array{Float64}()
                end
            end
        end
    end
end
```

```
        append!( fr_edge, [[
            vertices_a[mc],      vertices_a[mc_i],
            vertices_a[mc+2],    vertices_a[mc_i+2] ]]
    )

        append!( fr_edge, [[
            vertices_b[mc],      vertices_b[mc_i],
            vertices_b[mc+2],    vertices_b[mc_i+2] ]]
    )

        end
        append!(fr_edges, [ fr_edge ])
    end
end

end
fr_edges
end

function get_vertex(a,b,x,y)
    ((x*8)+(y*4))+(b+(a*2))+1
end

function float(n)
    convert(Float64,n)
end

function get_hyperedges(H, n)
    l = []
    for i = 1:size(H)[1]
        if any(x->x==n, H[i])
            append!(l,i)
        end
    end
    l
end

@model mdl() = begin
    z ~ Beta(1,1)
    a ~ Bernoulli(0.5)
    b ~ Bernoulli(0.5)
    x ~ Bernoulli(0.5)
    y ~ Bernoulli(0.5)
    c ~ Uniform(0.0, 1.0)
end

function generate_global_distribution(constraints,N)
    hyperedges = foulis_randall_product()
    hyperedges_tallies = zeros(12)
```



```
global_distribution = zeros(16)
while sum(global_distribution) < N
    r = sample mdl(), SMC(N))
```

## Running PyMC3 & Pyro

2

To run the file "pymc3-main.py", you will firstly need to install PyMC3 via the following page:

<https://docs.pymc.io/>

Then run the following command from the terminal:

Command

```
python "pymc3-main.py"
```

To run the file "pyro-main.py", you will firstly need to install Pyro via the following page:

<http://pyro.ai/>

Then run the following command from the terminal:

Command

```
python "pyro-main.py"
```

```
function accuracy_time(N)
```



## Running Turing.jl

3

To run the Turing implementation, you will need to install Julia:

<https://julialang.org/>

Then install both the "Distributions" package, and "Turing" package from within the Julia package manager.

Finally, run the implementation using the following command:

Command

```
julia "turing-main.jl"
```

```
println(p[9]+p[10]+p[15]+p[16])
```

## Running Figaro

4

The Figaro implementation will require the following software:

Software

IntelliJ IDEA

NAME

Jetbrains

DEVELOPER

Create a new project, and add the following jar to your project "figaro\_2.11-5.0.0.0-sources.jar" from the Figaro web page:

<https://www.cra.com/work/case-studies/figaro>

Then run the implementation from within the IntelliJ IDEA Community Edition IDE.

```
accuracy_time(5000,  
accuracy_time(6000)
```



```
-  
accuracy_time(7000)  
accuracy_time(8000)  
accuracy_time(9000)  
accuracy_time(10000)  
accuracy_time(15000)  
accuracy_time(20000)  
accuracy_time(25000)  
accuracy_time(30000)  
accuracy_time(35000)  
accuracy_time(40000)  
accuracy_time(45000)  
accuracy_time(50000)  
accuracy_time(55000)  
accuracy_time(60000)  
accuracy_time(65000)  
accuracy_time(70000)  
accuracy_time(75000)  
accuracy_time(80000)  
accuracy_time(85000)  
accuracy_time(90000)  
accuracy_time(95000)  
accuracy_time(100000)
```