CS423: Probabilistic Programming
Introduction

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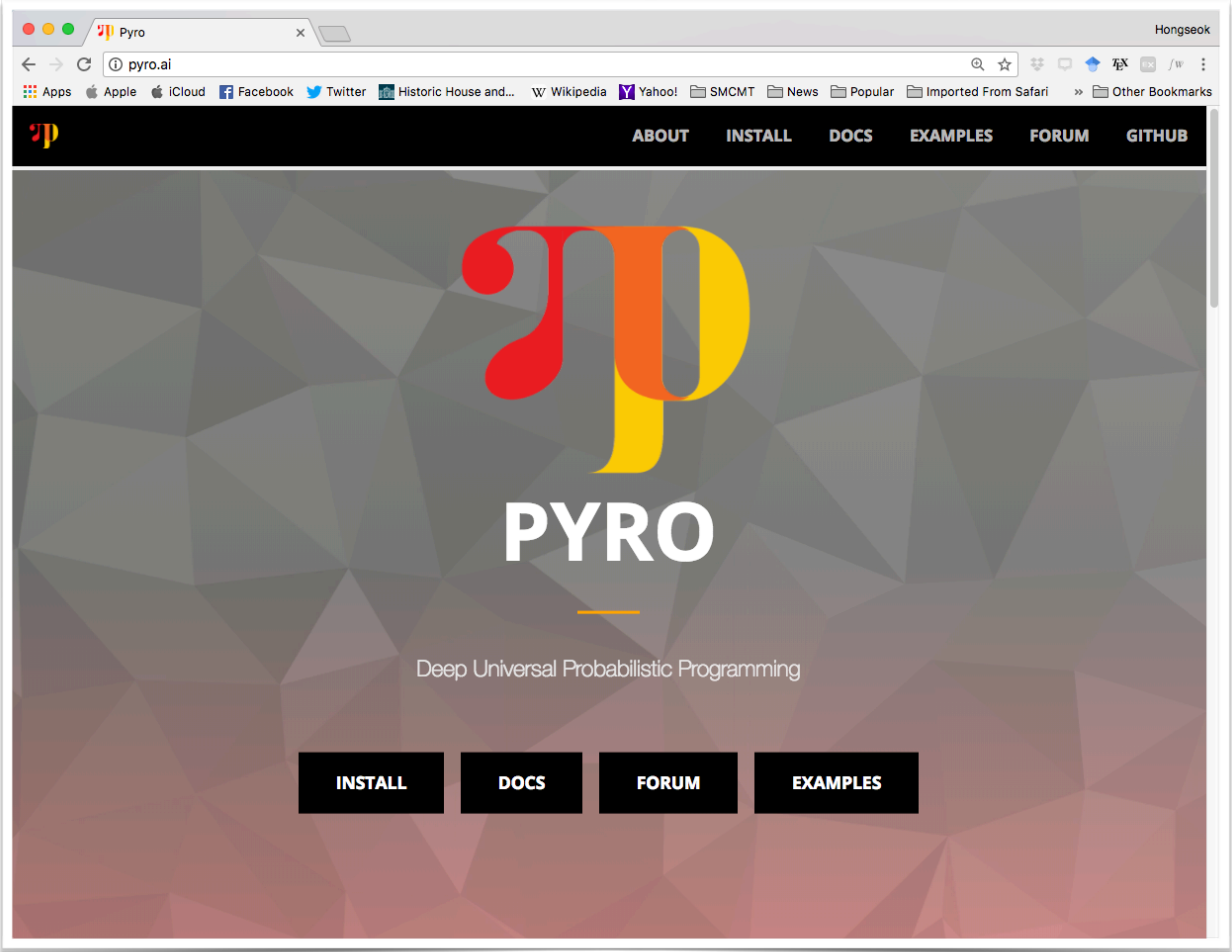
KAIST

Can we capture the origins of human common sense … in engineering terms? … New tools from probabilistic programming, game engines and program learning … are beginning to let us answer these questions.

Josh Tenenbaum
Invited talk at ICML'18 & IJCAI'18

This Review … discusses some of the state-of-the-art advances in the field, namely, probabilistic programming, Bayesian optimization, data compression and automatic model discovery.

Zoubin Gharahmani
2015 Nature Review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What is probabilistic programming?

(Bayesian) probabilistic modelling of data

1. Develop a new probabilistic (generative) model.
2. Design an inference algorithm for the model.
3. Using the algo., fit the model to the data.

(Bayesian) probabilistic modelling of data

in a prob. prog. language

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as a program

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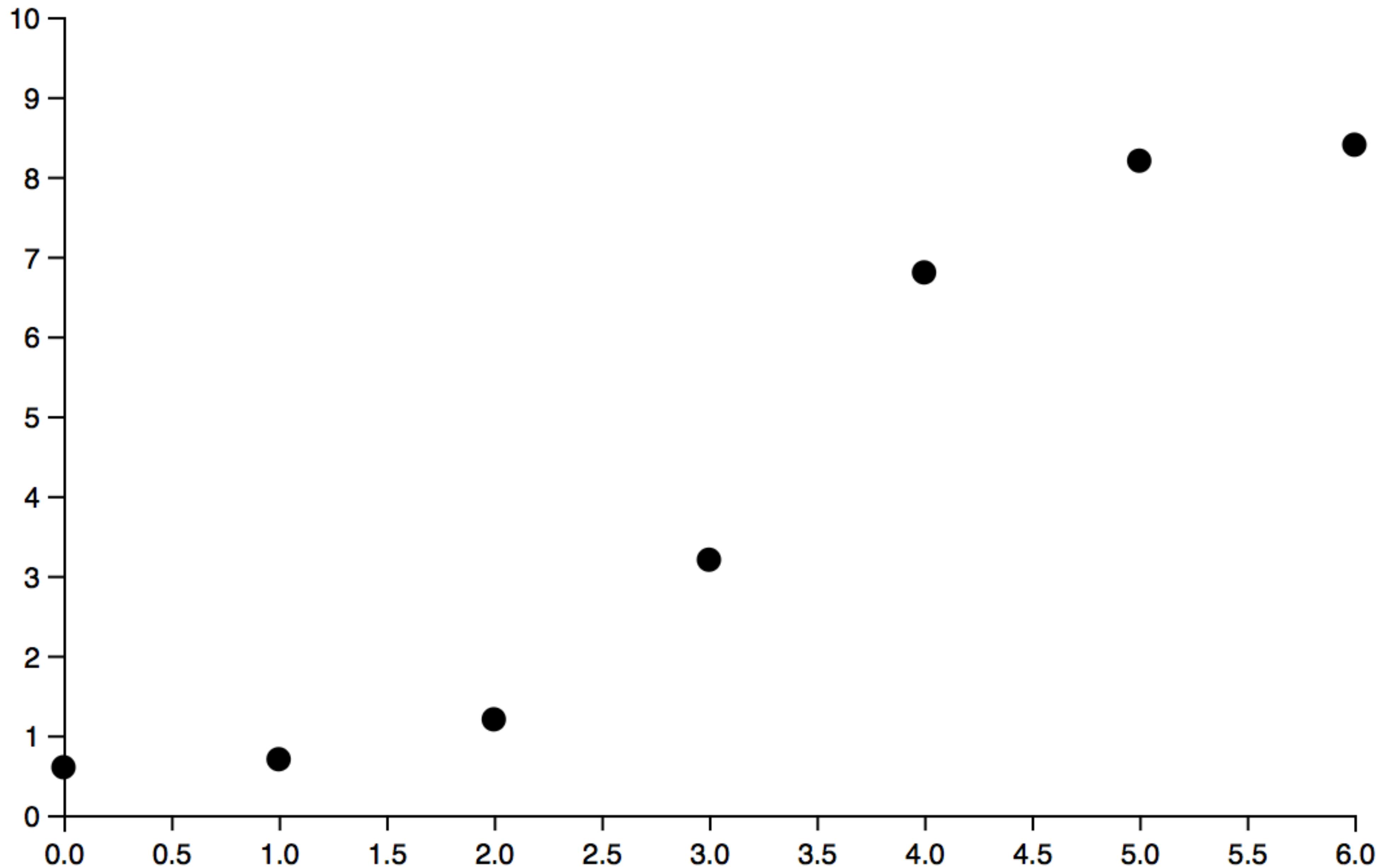
as a program

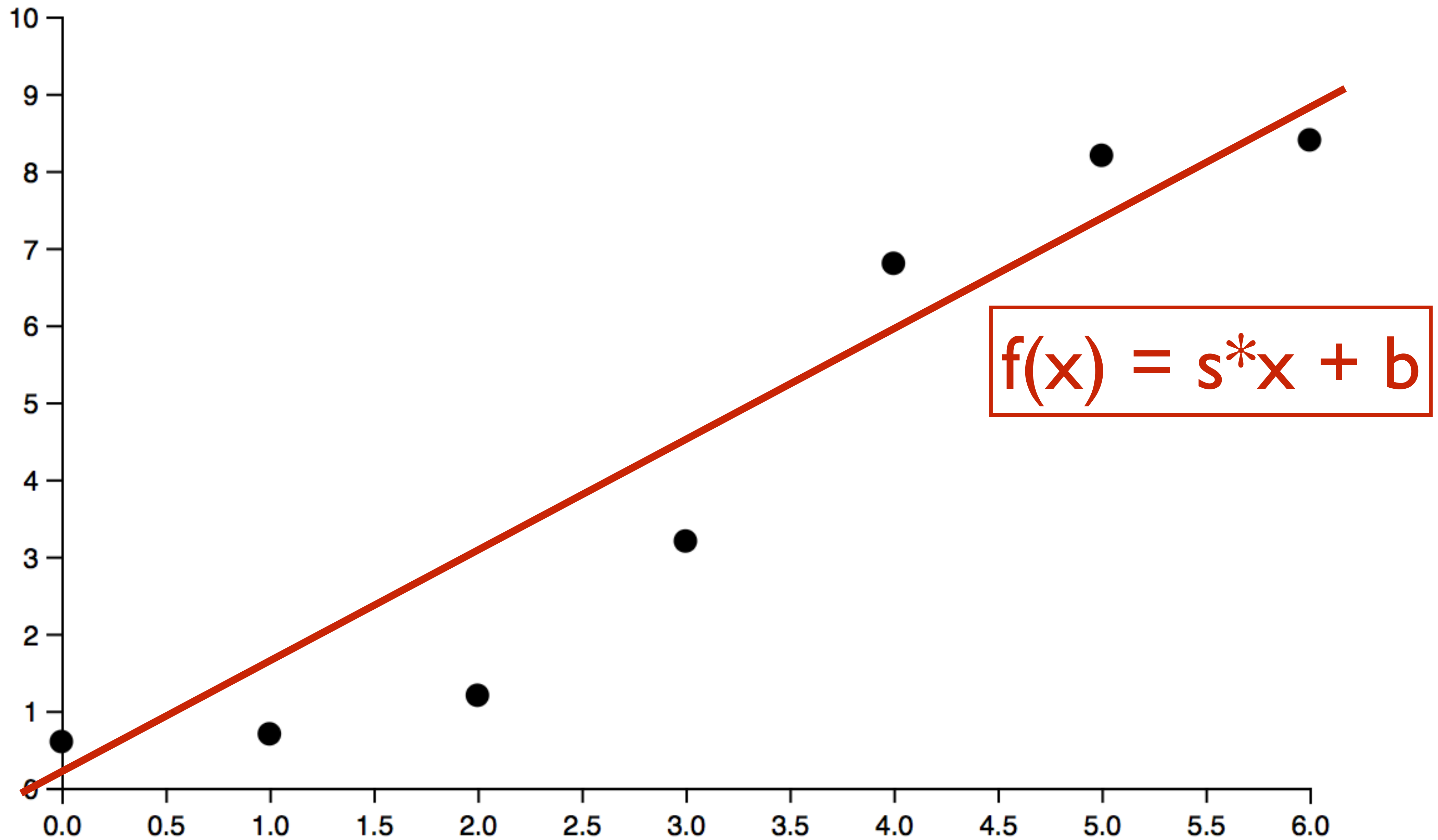
1. Develop a new probabilistic (generative) model.
2. ~~Design an inference algorithm for the model.~~
3. Using ~~the algo.~~, fit the model to the data.

a generic inference algo.
of the language

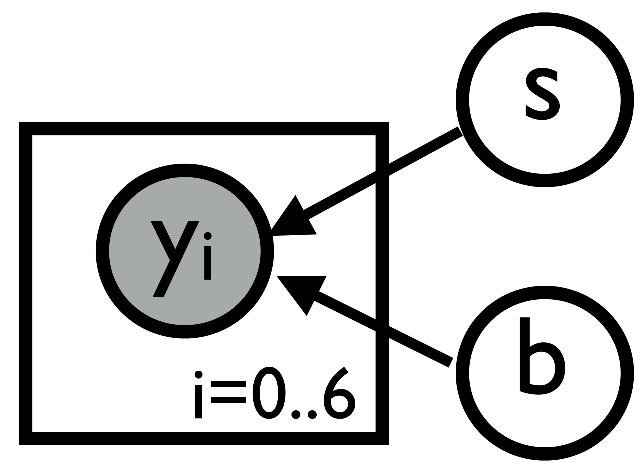
Line fitting



Line fitting



Bayesian generative model



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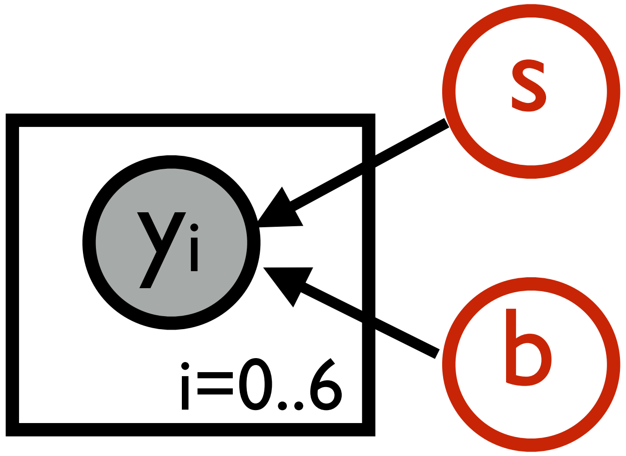
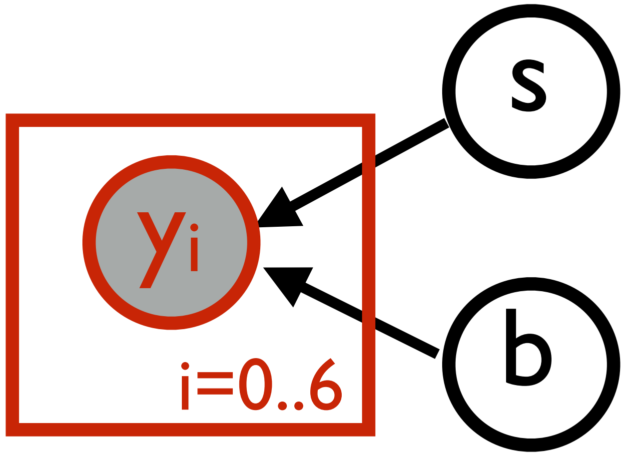


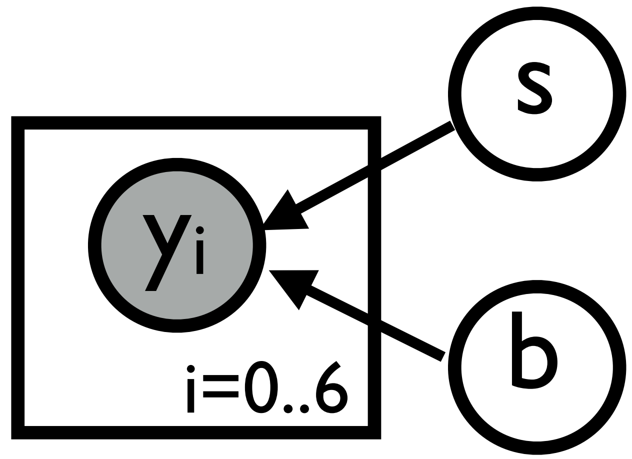

```
s      ~ normal(0, 2)
b      ~ normal(0, 6)
```

Bayesian generative model




```
s     ~ normal(0, 2)
b     ~ normal(0, 6)
f(x)  = s*x + b
yi     ~ normal(f(i), 0.5)
             where i = 0 .. 6
```

Bayesian generative model

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            where i = 0 .. 6
```

Q: posterior of (s,b) given y_0=0.6, …, y_6=8.4?

Posterior of s and b given y_i's

$$p(s, b \mid y_0, .., y_6) = \frac{p(y_0, .., y_6 \mid s,b) \times p(s,b)}{p(y_0, .., y_6)}$$

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Anglican program

```
(let [s (sample (normal 0 2))
      b (sample (normal 0 6))
      f (fn [x] (+ (* s x) b))]
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Anglican program

```
(let [s (sample (normal 0 2))
      b (sample (normal 0 6))
      f (fn [x] (+ (* s x) b))]

    (observe (normal (f 0) 0.5) 0.6)
    (observe (normal (f 1) 0.5) 0.7)
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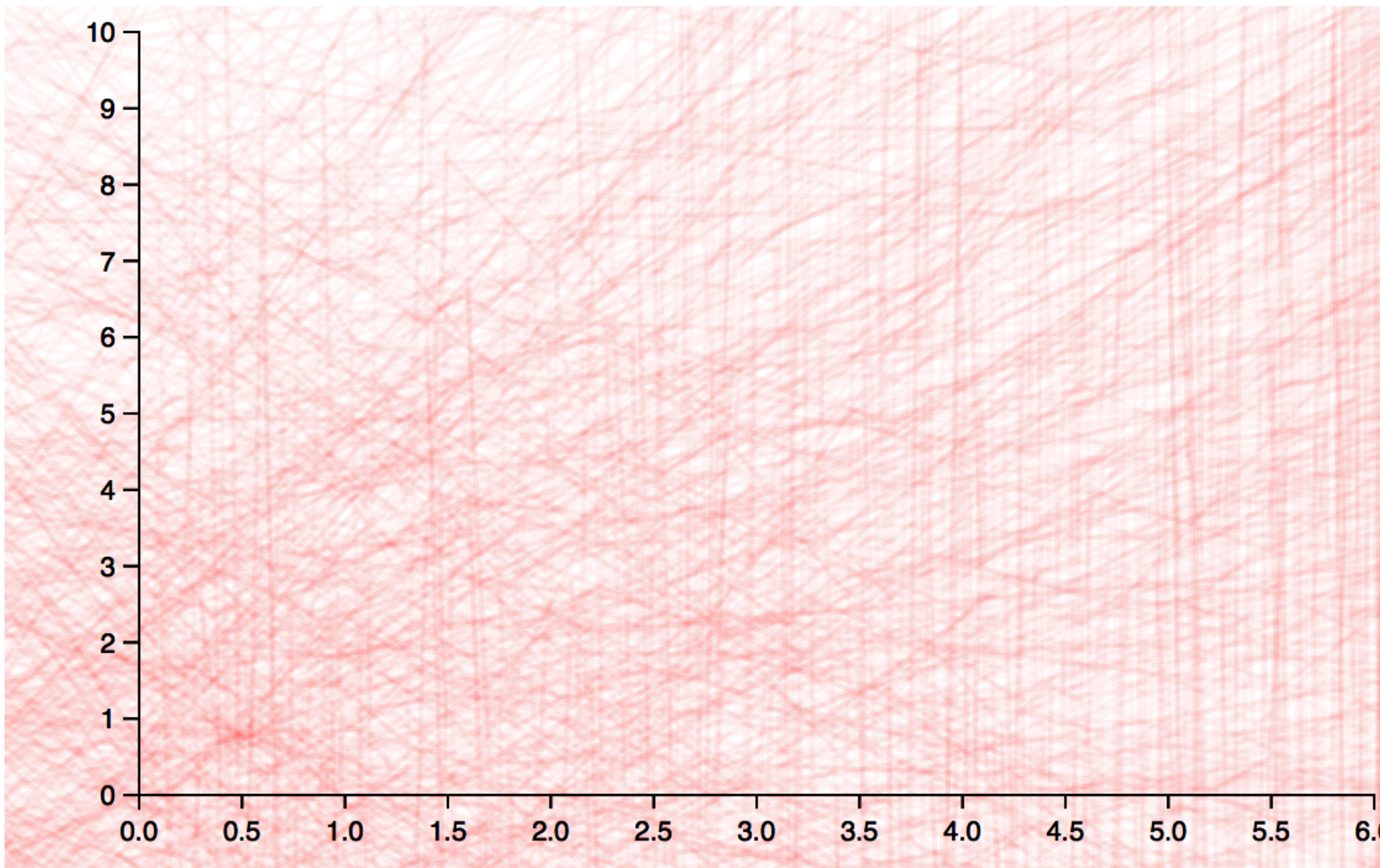
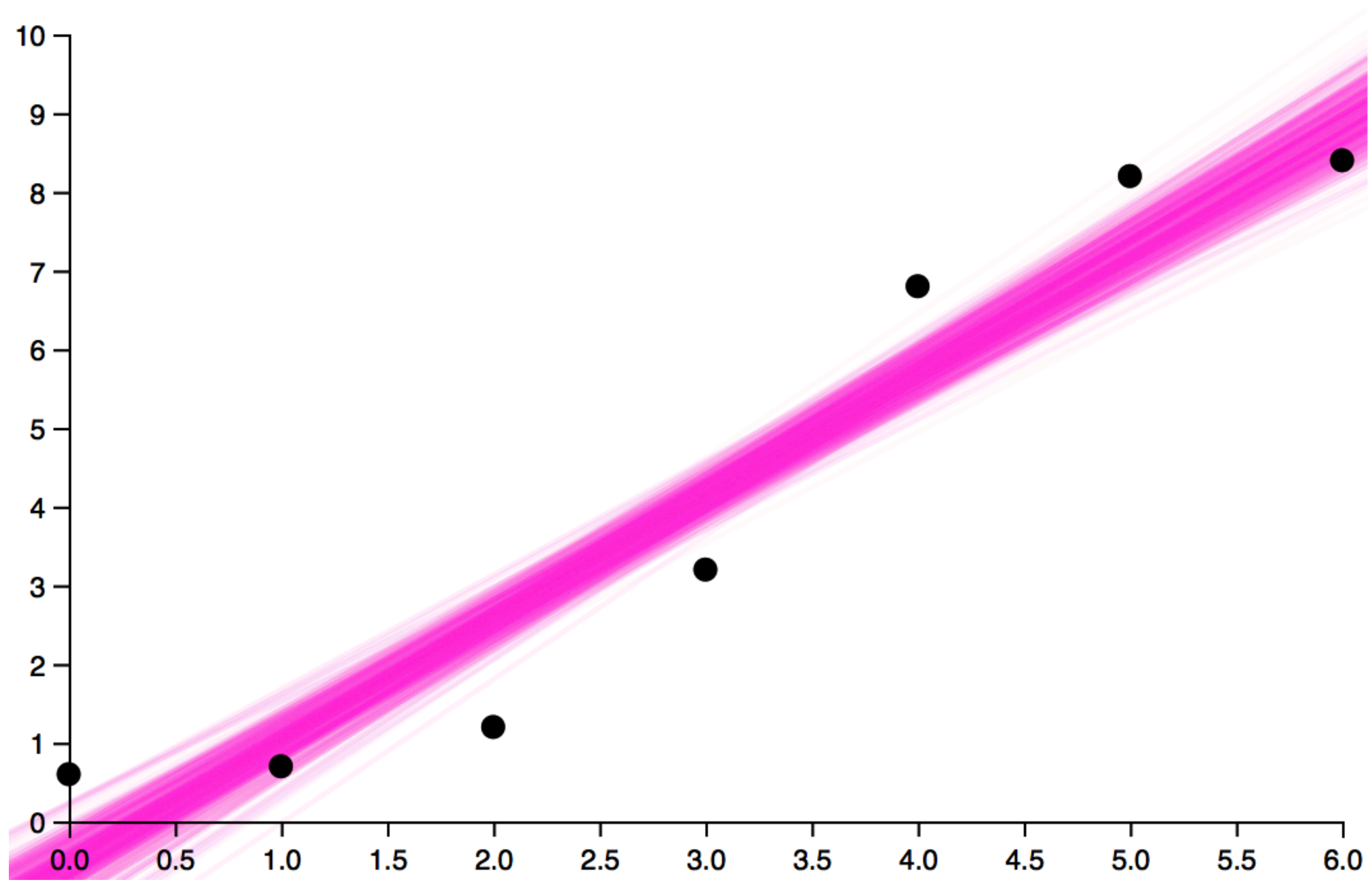
  [s b])
```

Samples from prior



Samples from posterior

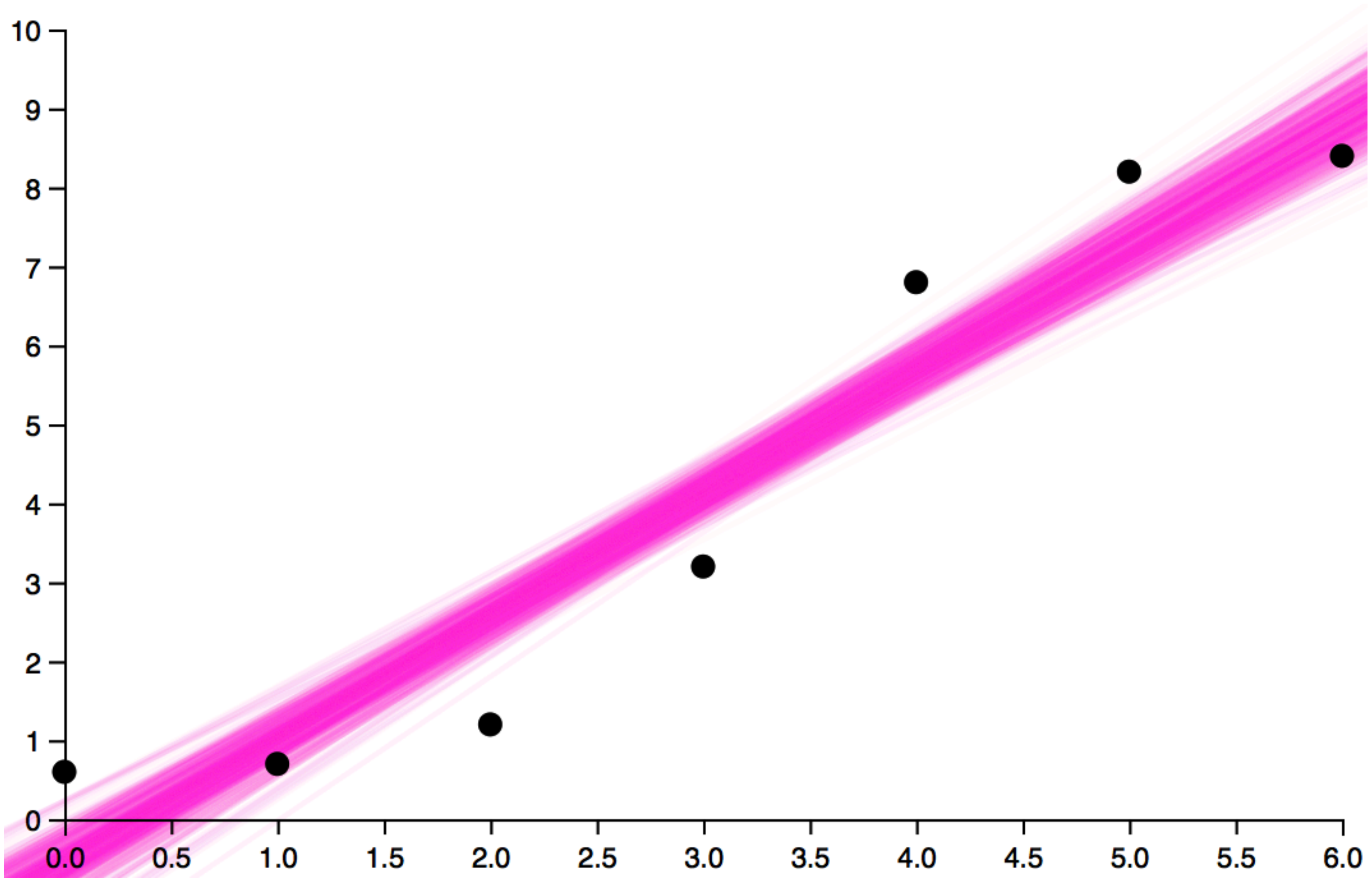


Why should one care about prob. programming?

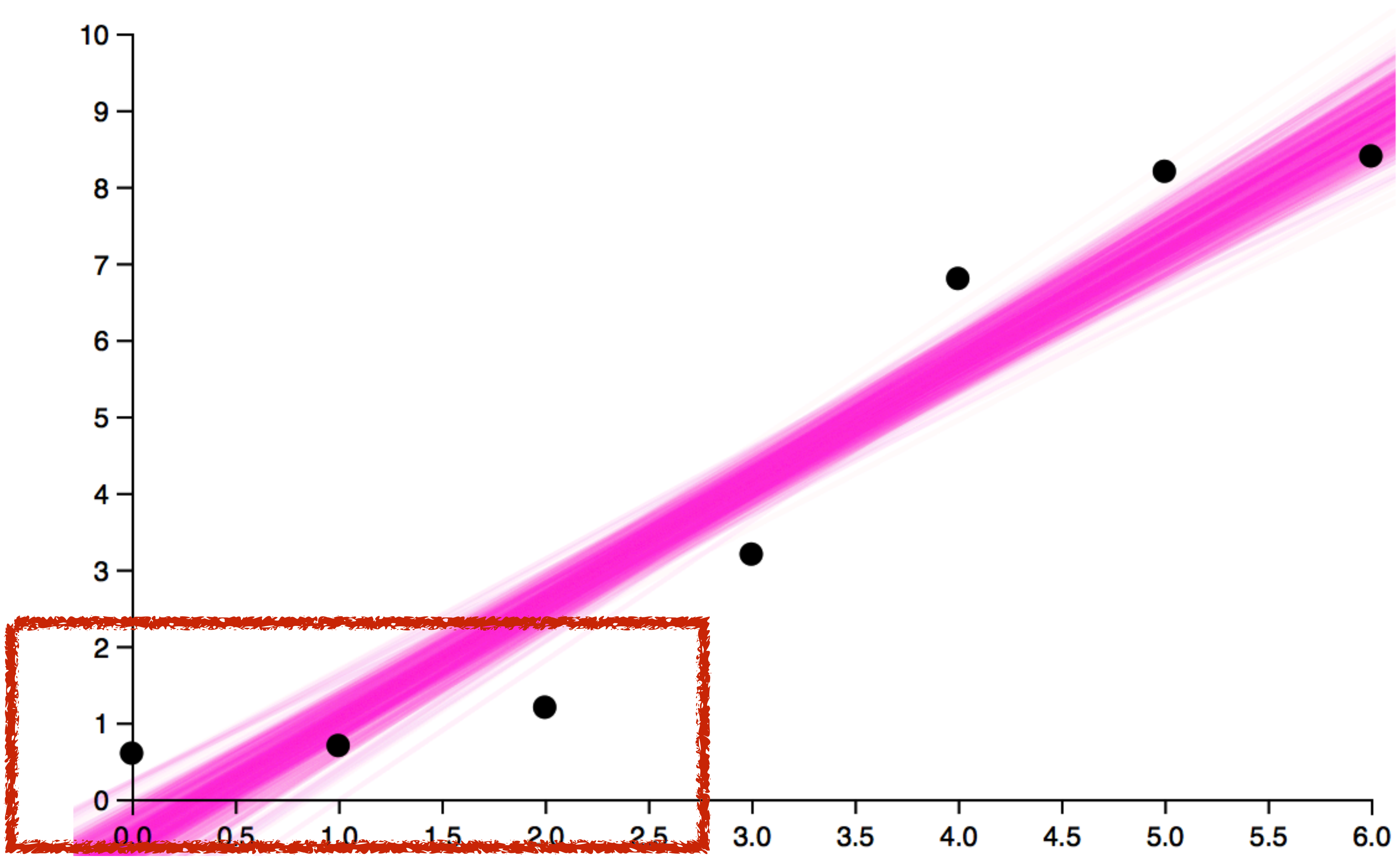
"Because probabilistic programming is a good way to build an AI." (My ML colleague)

Prob. programming languages enable one to build and explore highly complex models.

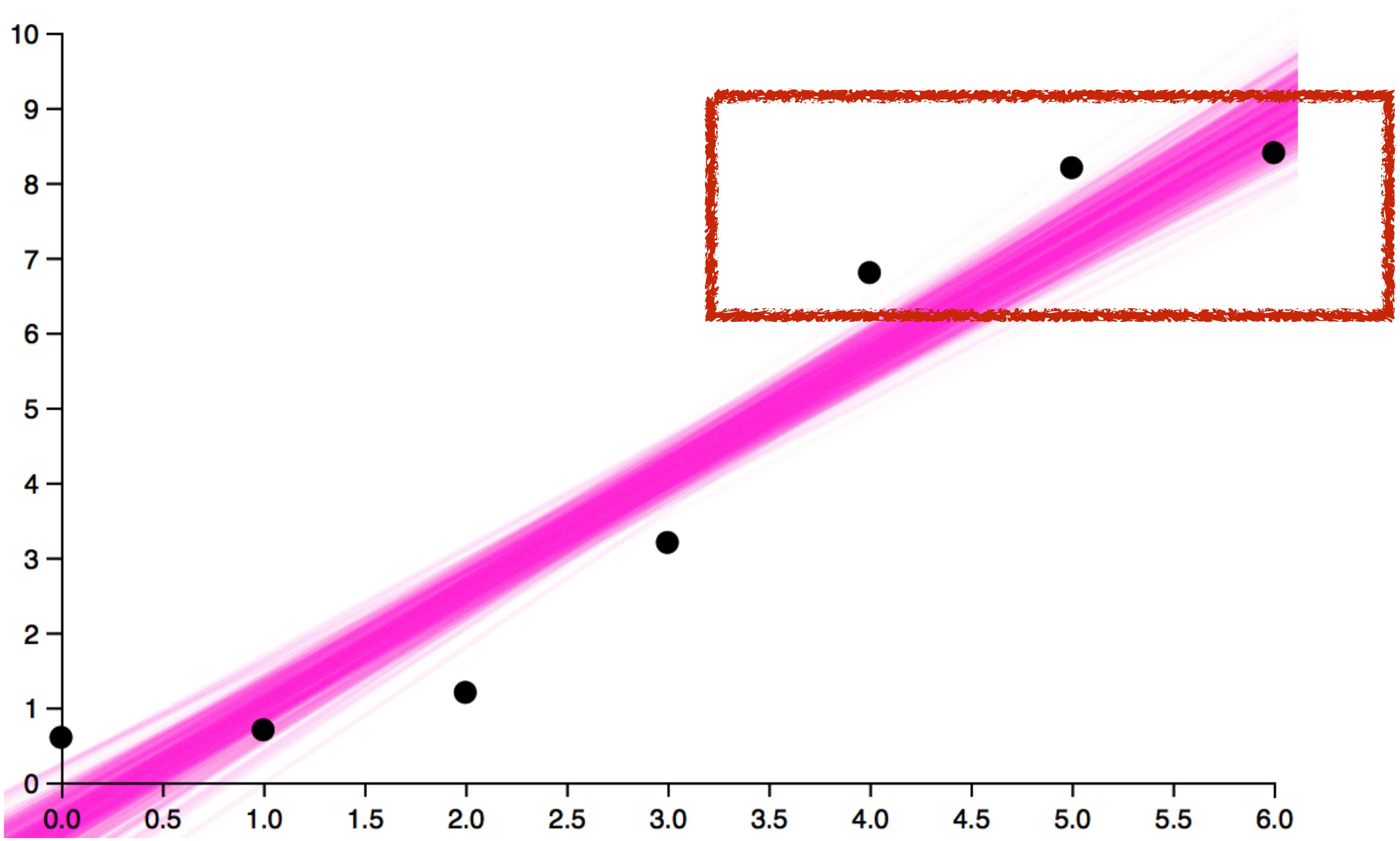
Underfit?



Underfit?



Underfit?



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  [s b])
```

Functions as first-class citizen.

```
(let [s (sample (normal 0 2))
      b (sample (normal 0 6))
      f (fn [x] (+ (* s x) b))]

    (observe (normal (f 0) 0.5) 0.6)
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  [s b])
  f)
```

Functions as first-class citizen.

```
(let [F (fn []
          (let [s (sample (normal 0 2))
                b (sample (normal 0 6))]
            (fn [x] (+ (* s x) b))))
      f (F)]
    (observe (normal (f 0) 0.5) 0.6)
    (observe (normal (f 1) 0.5) 0.7)
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  ~~[s b])~~
   f)
```

Functions as first-class citizen.

```
(let [F (fn []
          (let [s (sample (normal 0 2))
                b (sample (normal 0 6))]
            (fn [x] (+ (* s x) b))))
      f (add-change-points F 0 6)]
    (observe (normal (f 0) 0.5) 0.6)
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  [s b])
  f)
```

Functions as first-class citizen.

```
(defm add-change-points [F l u]
  (if (sample (flip 0.5)) (F)
    (if (sample (flip 0.5))
       (let [cp1 (sample
                   (uniform-continuous l u))
             f1 (F)
             f2 (F)]
         (fn [x] (if (< x cp1) (f1 x) (f2 x))))
       (let [cp1 (sample
                   (uniform-continuous l u))
             cp2 (sample
                   (uniform-continuous cp1 u))
             f1 (F)
             f2 (F)
             f3 (F)]
         (fn [x] (if (< x cp1) (f1 x)
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                       (f3 x)))))))))
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            cp2 (sample
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            f1 (F)
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            f3 (F)]
        (fn [x] (if (< x cp1) (f1 x)
                   (if (< x cp2) (f2 x)
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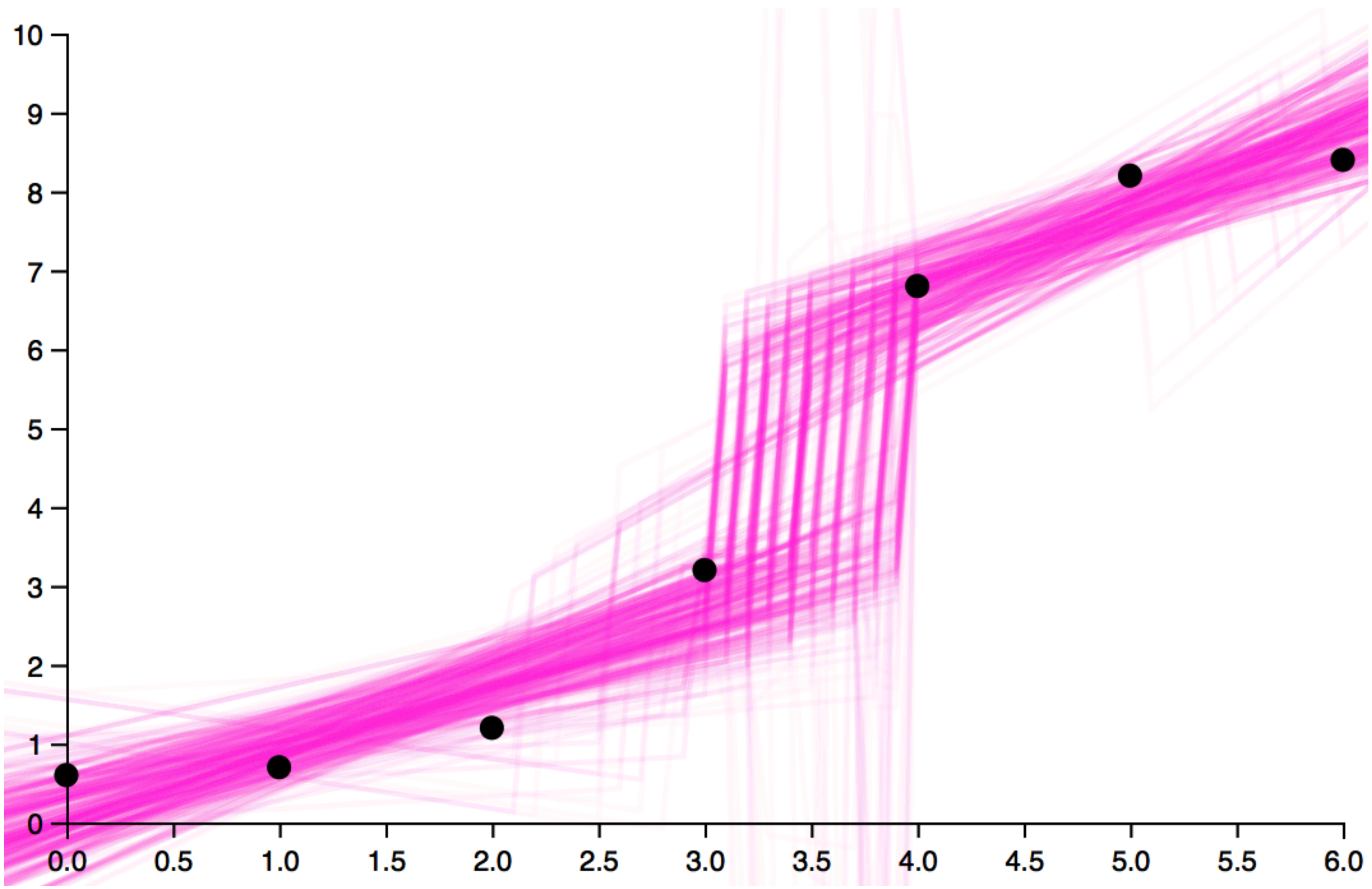
```

Samples from posterior



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~~[s b])~~
`f)`

[Q] Change the model so that it finds constant functions with change points.

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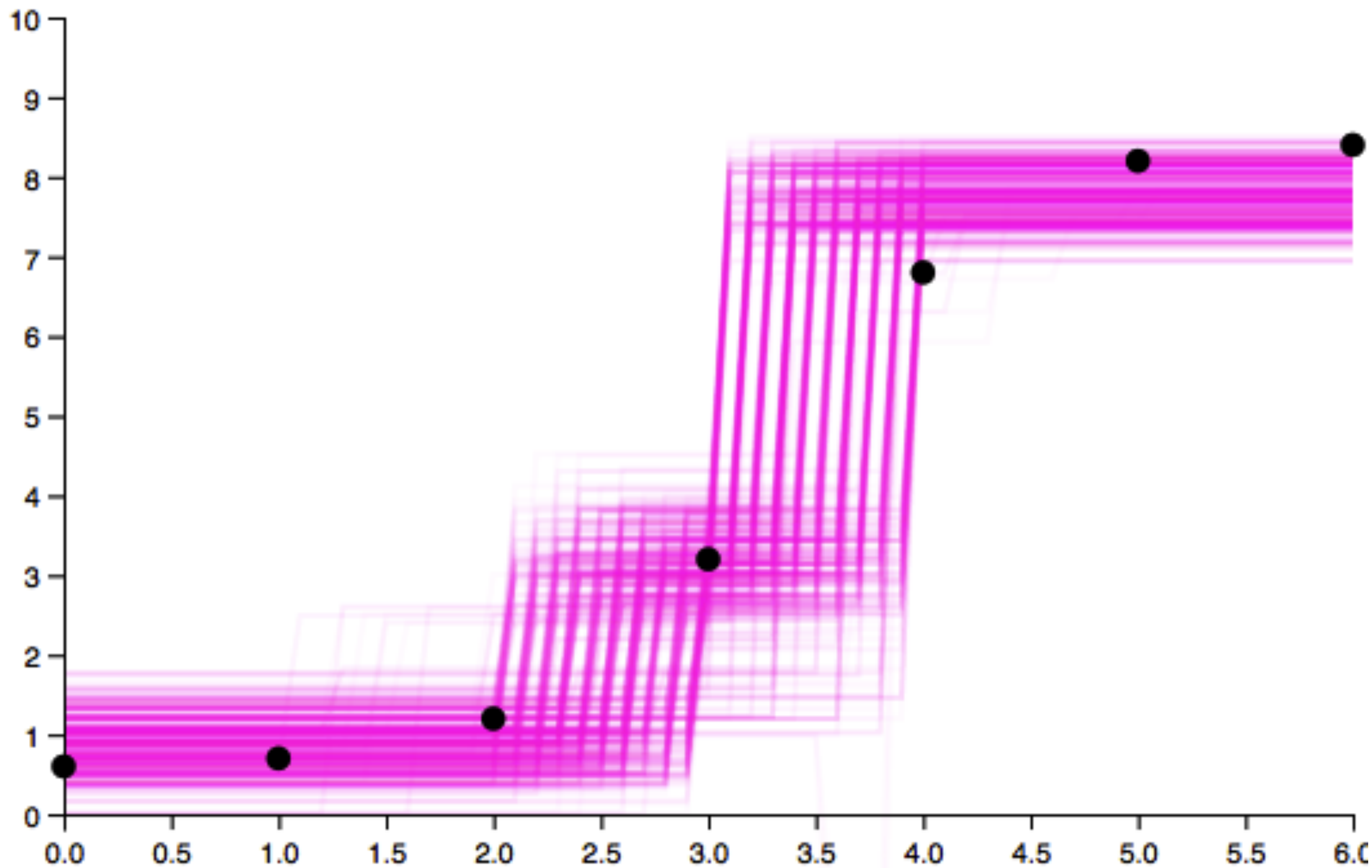
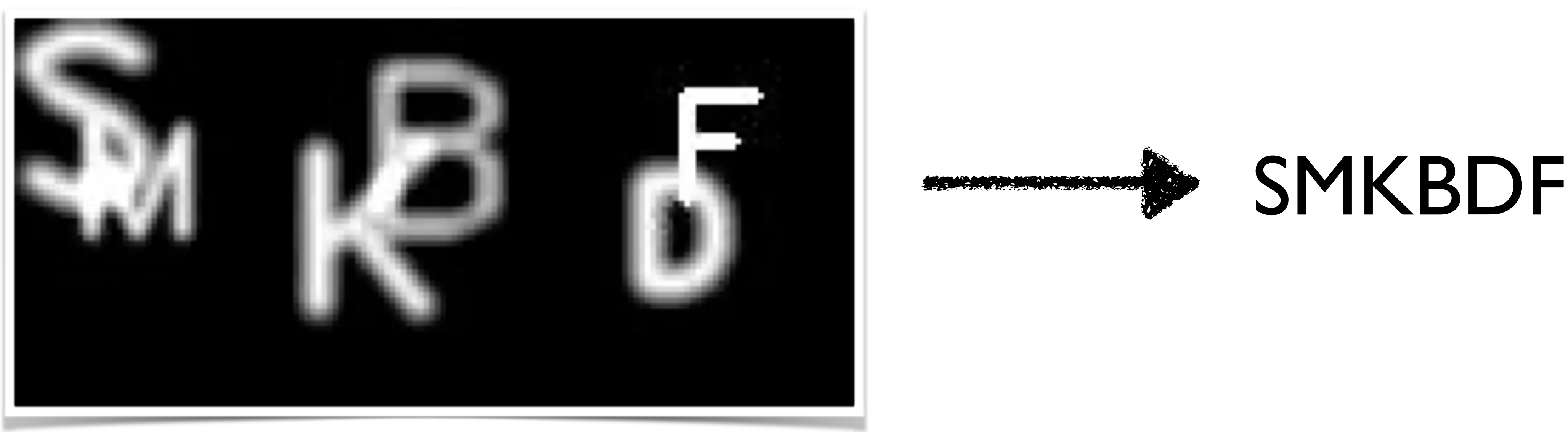


Three success stories: 1) captcha breaking



Le, Baydin, Wood [2016]

Three success stories: 1) captcha breaking

1. Sample a string.

Le, Baydin, Wood [2016]

Three success stories:
1) captcha breaking

SMKBDF

1. Sample a string.
2. Generate an image using complex JVM code.

Le, Baydin, Wood [2016]

Three success stories: 1) captcha breaking

Anglican's inference engine based on neural nets

→ SMKBDF

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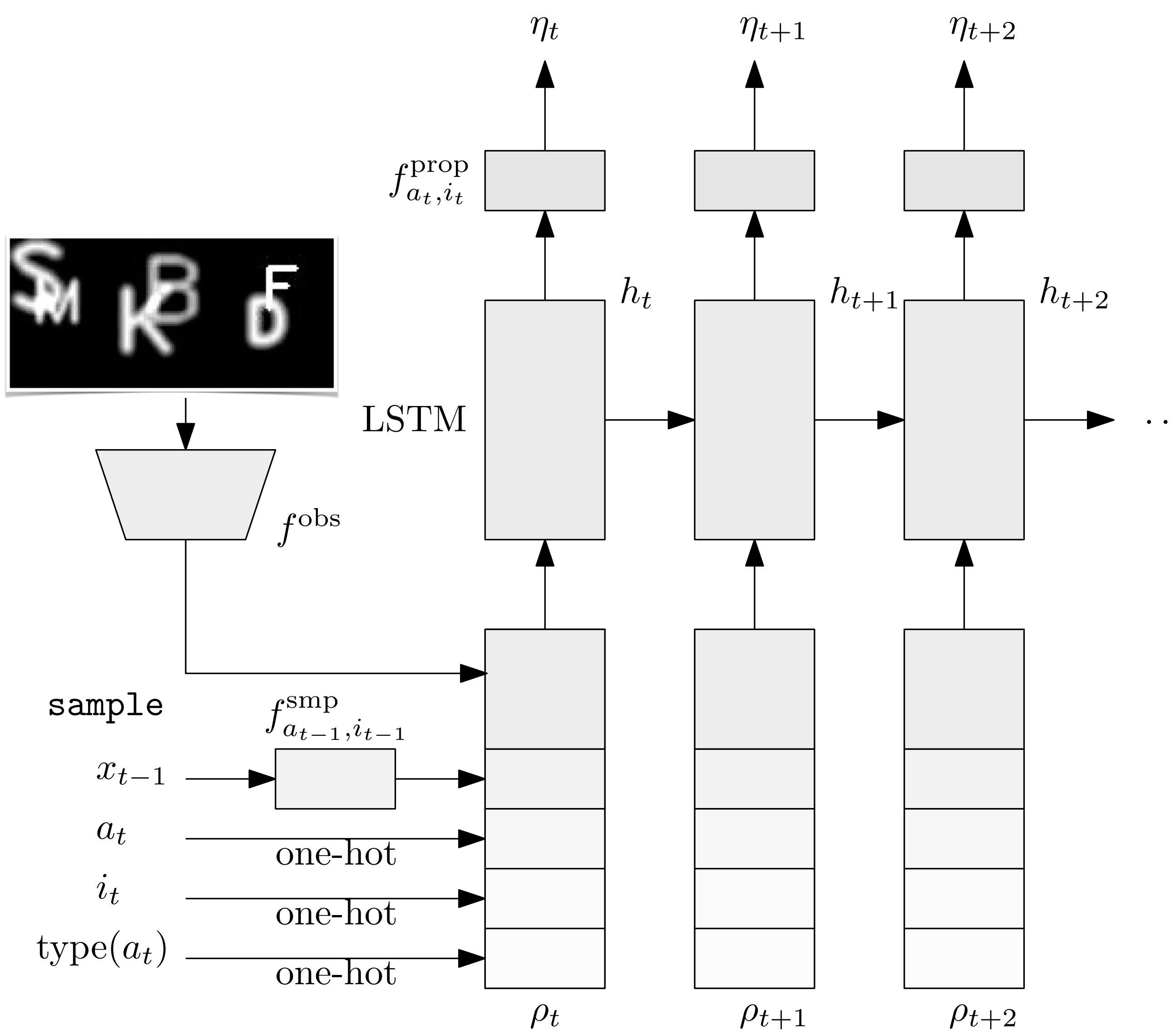
Le, Baydin, Wood [2016]

Three success stories: 1) captcha breaking



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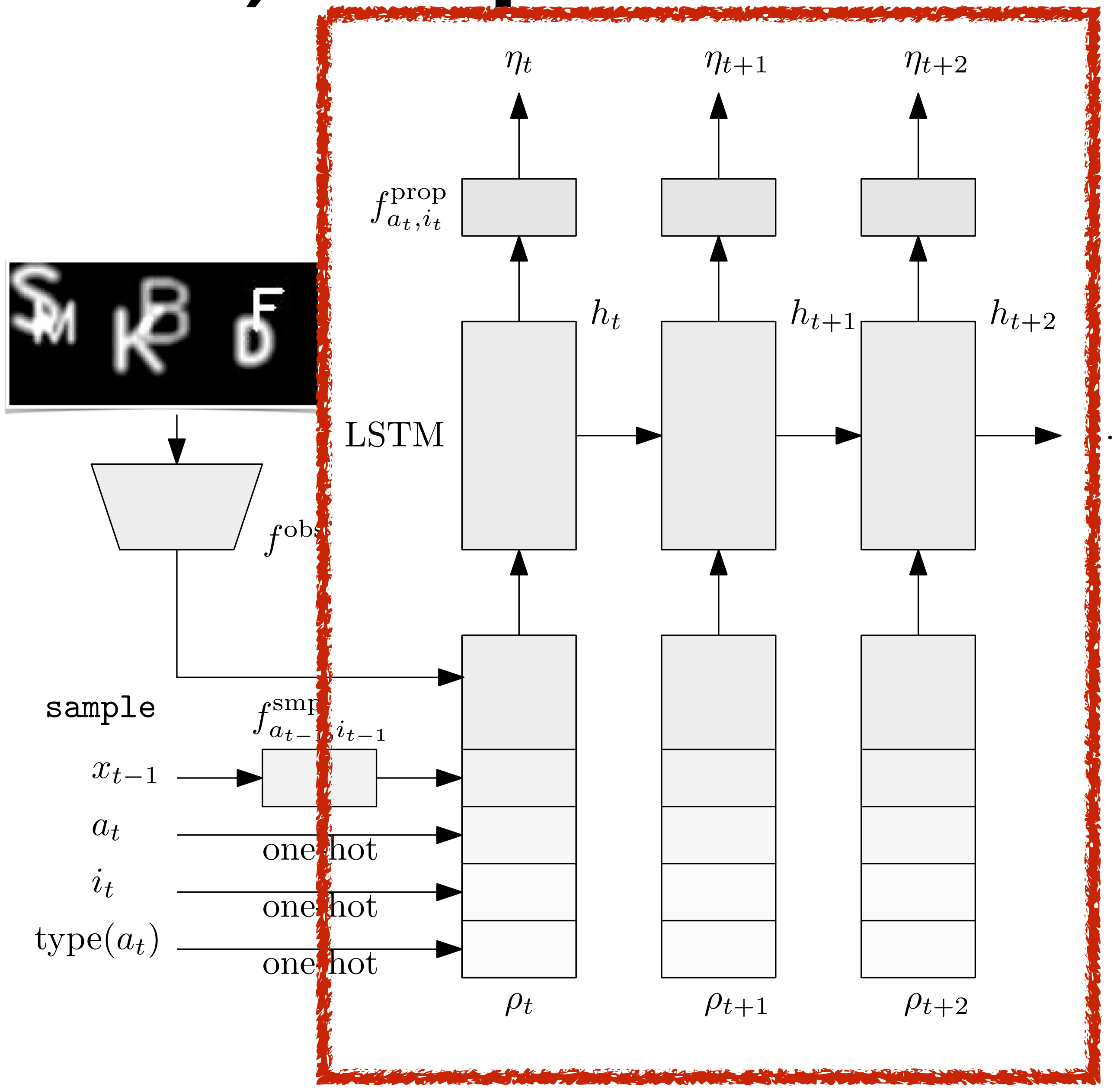

Neural net as a part of inference engine.

Le, Baydin, Wood [2016]

Three success stories:
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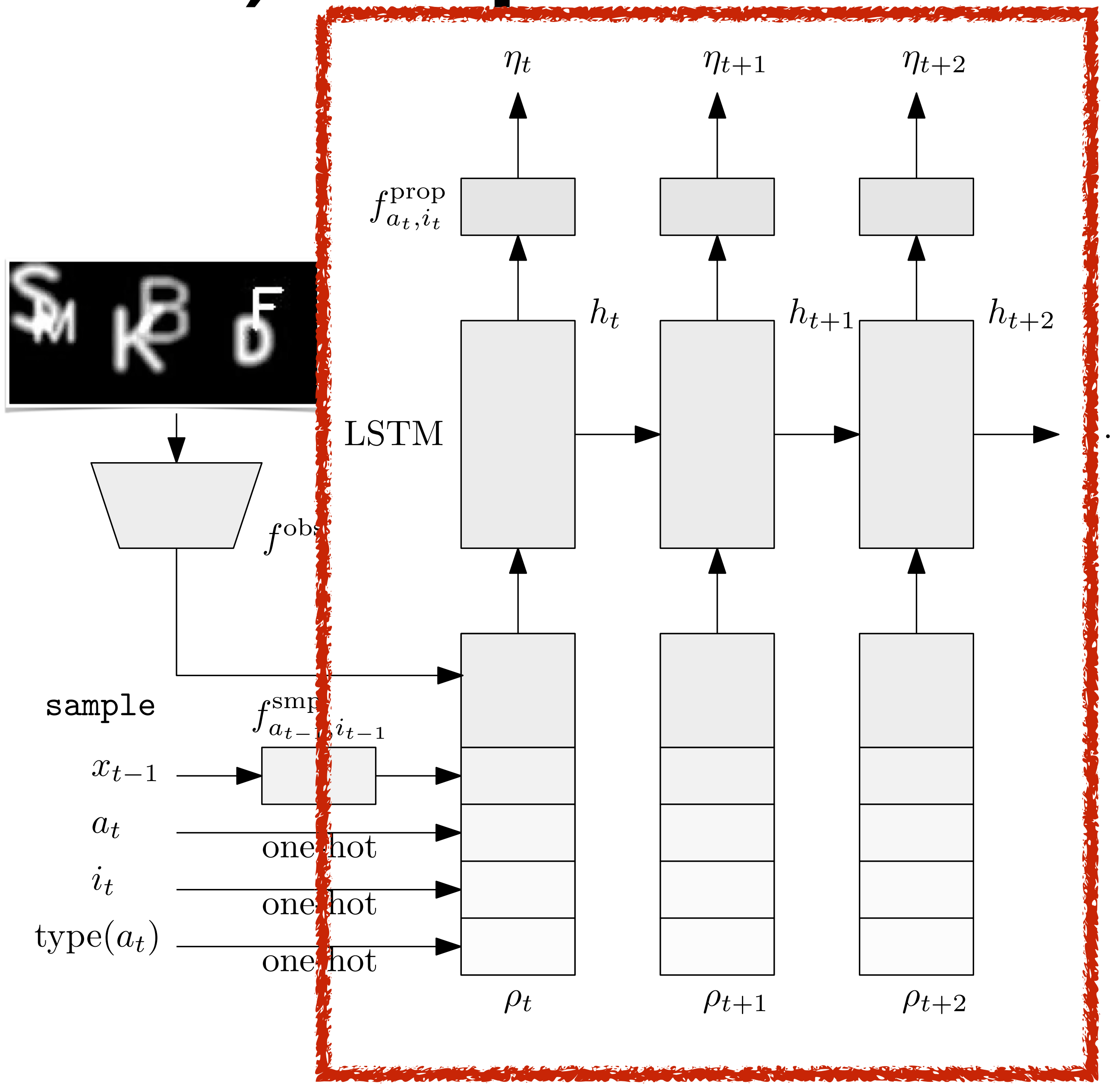
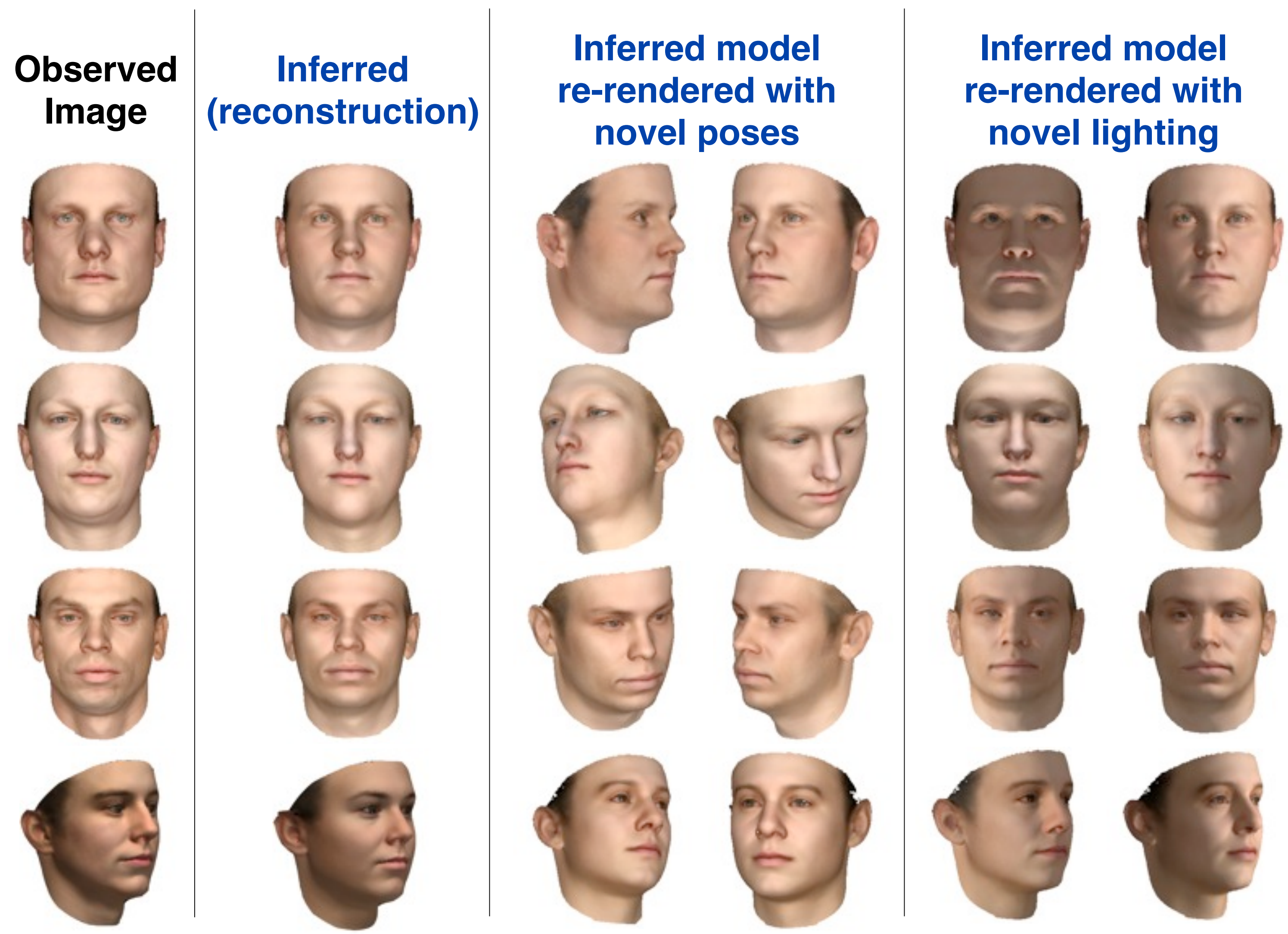


Neural net as a part of inference engine.

Approximates the inverse of the Captcha program.

Le, Baydin, Wood [2016]

Three success stories:
2) inverse graphics



Kulkarni, Kohl, Tenenvaum, Mansinghka [CVPR'15]

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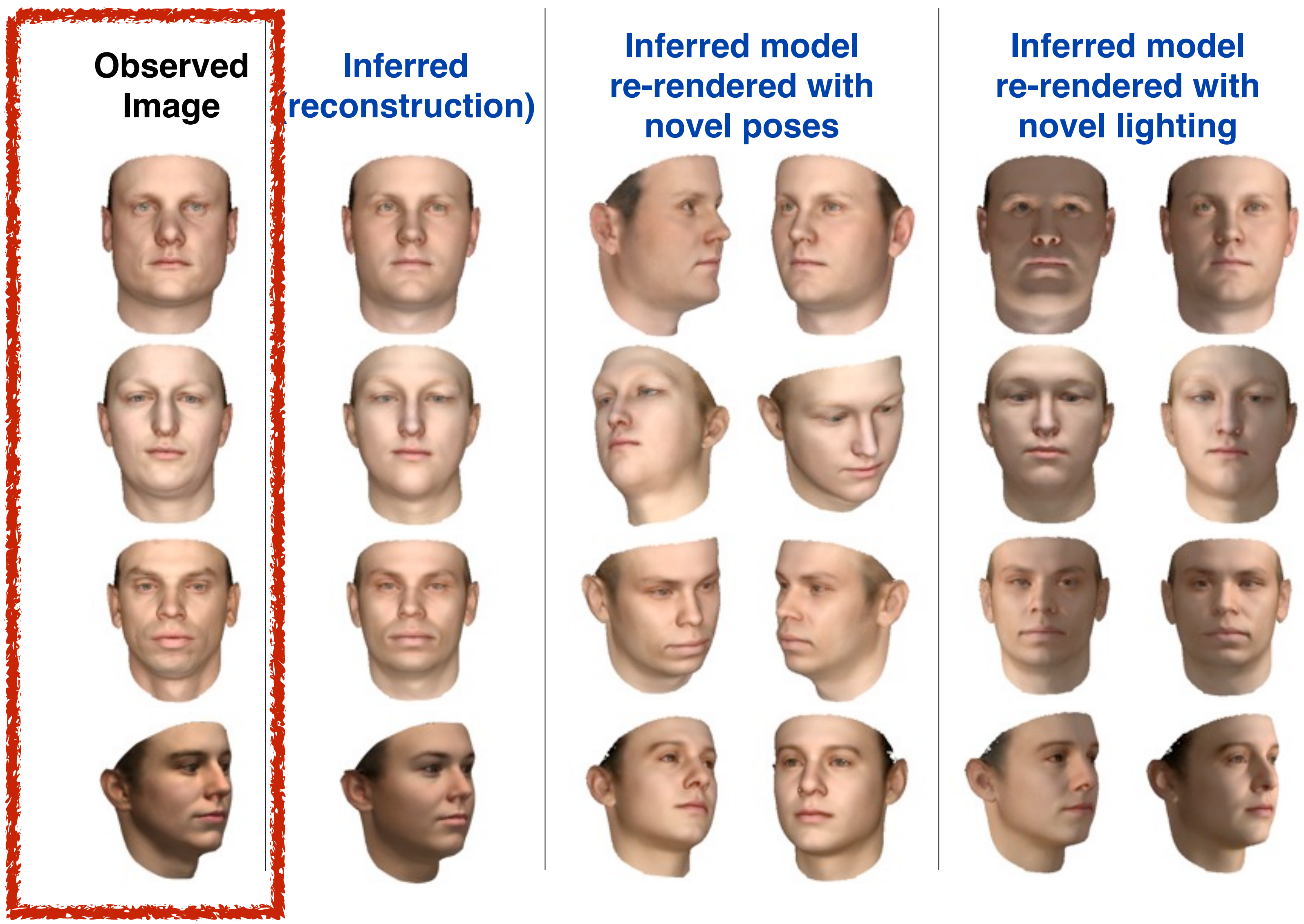

Image

Kulkarni, Kohl, Tenenvaum, Mansinghka [CVPR'15]

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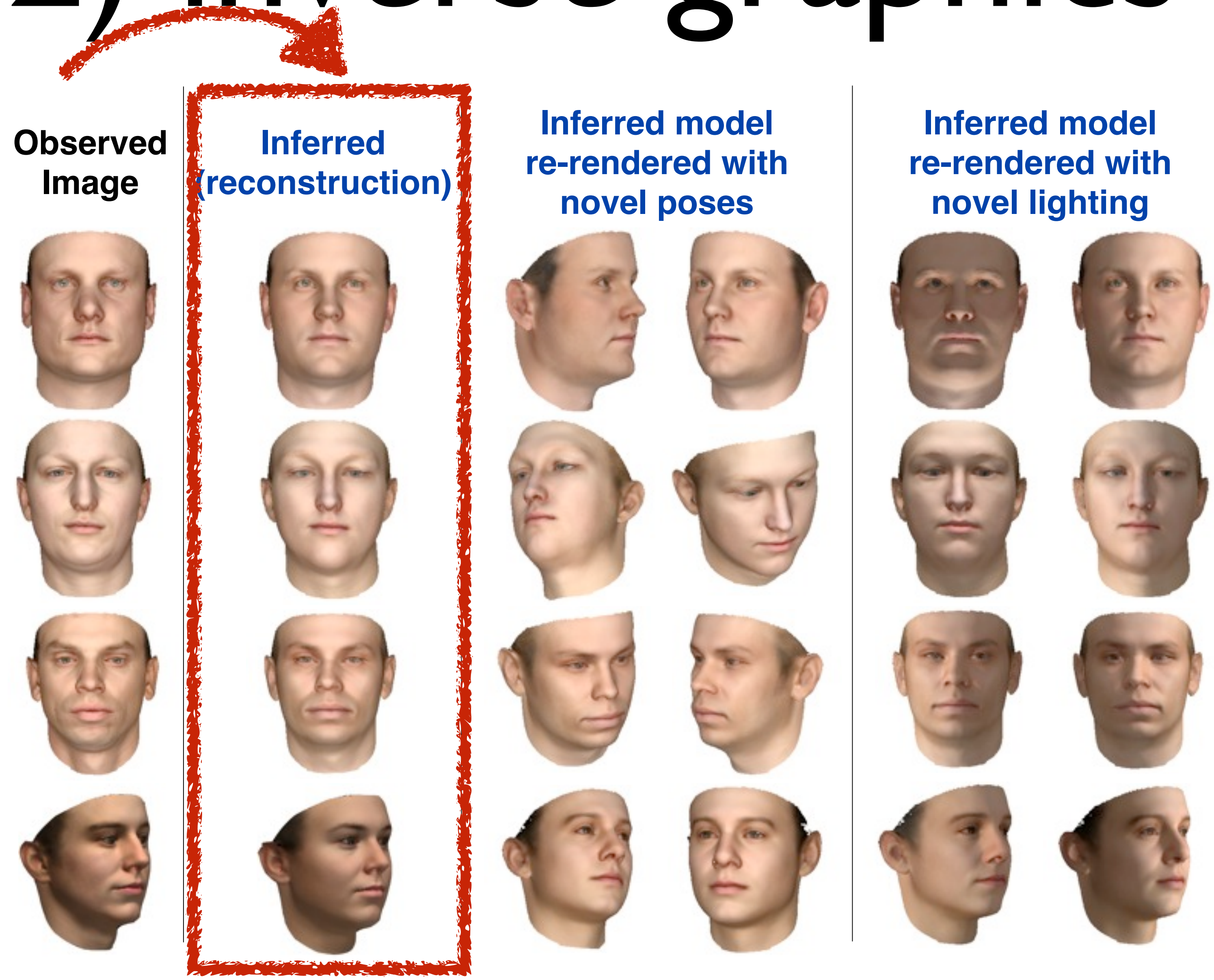
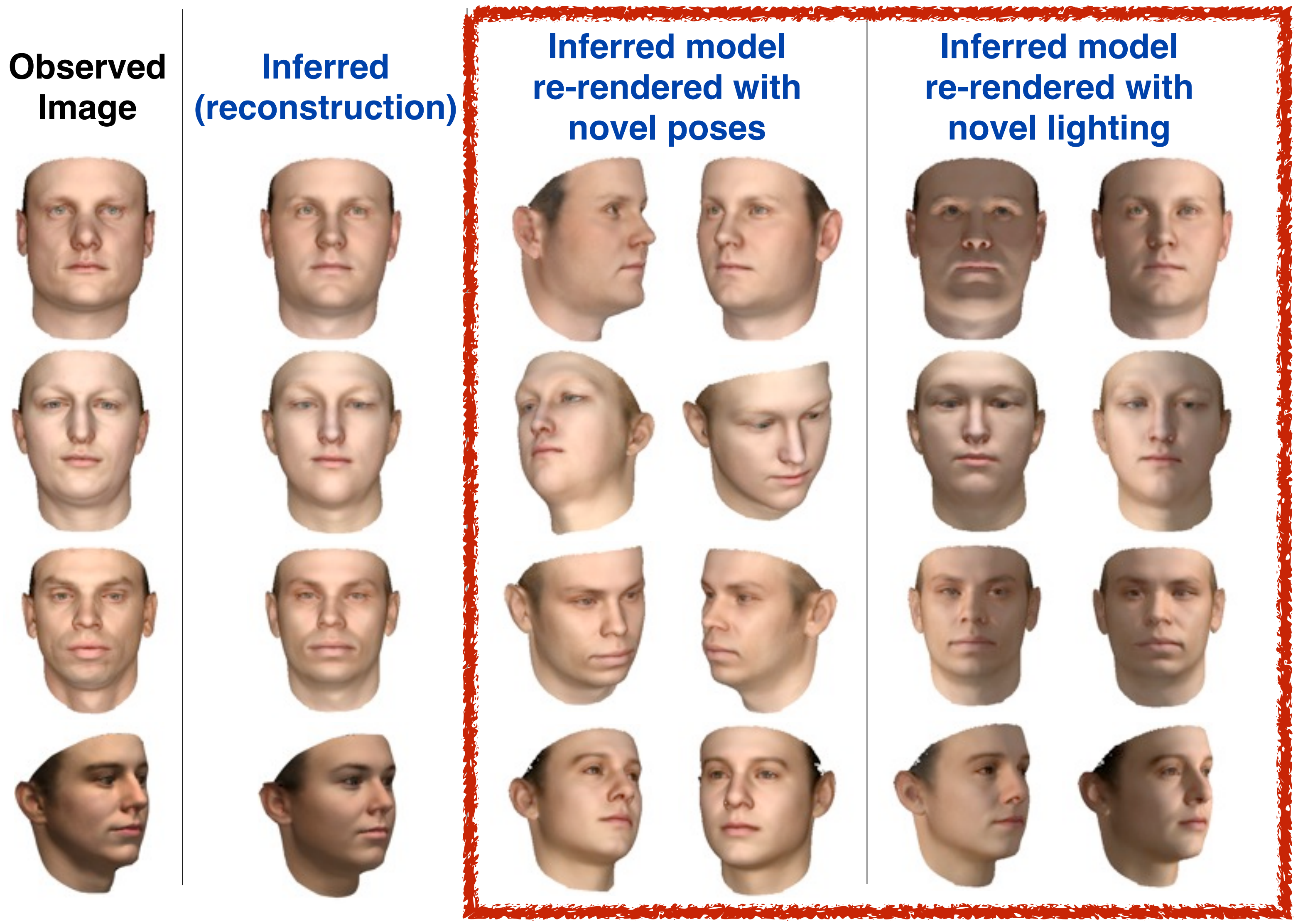


3D model

Kulkarni, Kohl, Tenenvaum, Mansinghka [CVPR'15]

Three success stories:
2) inverse graphics

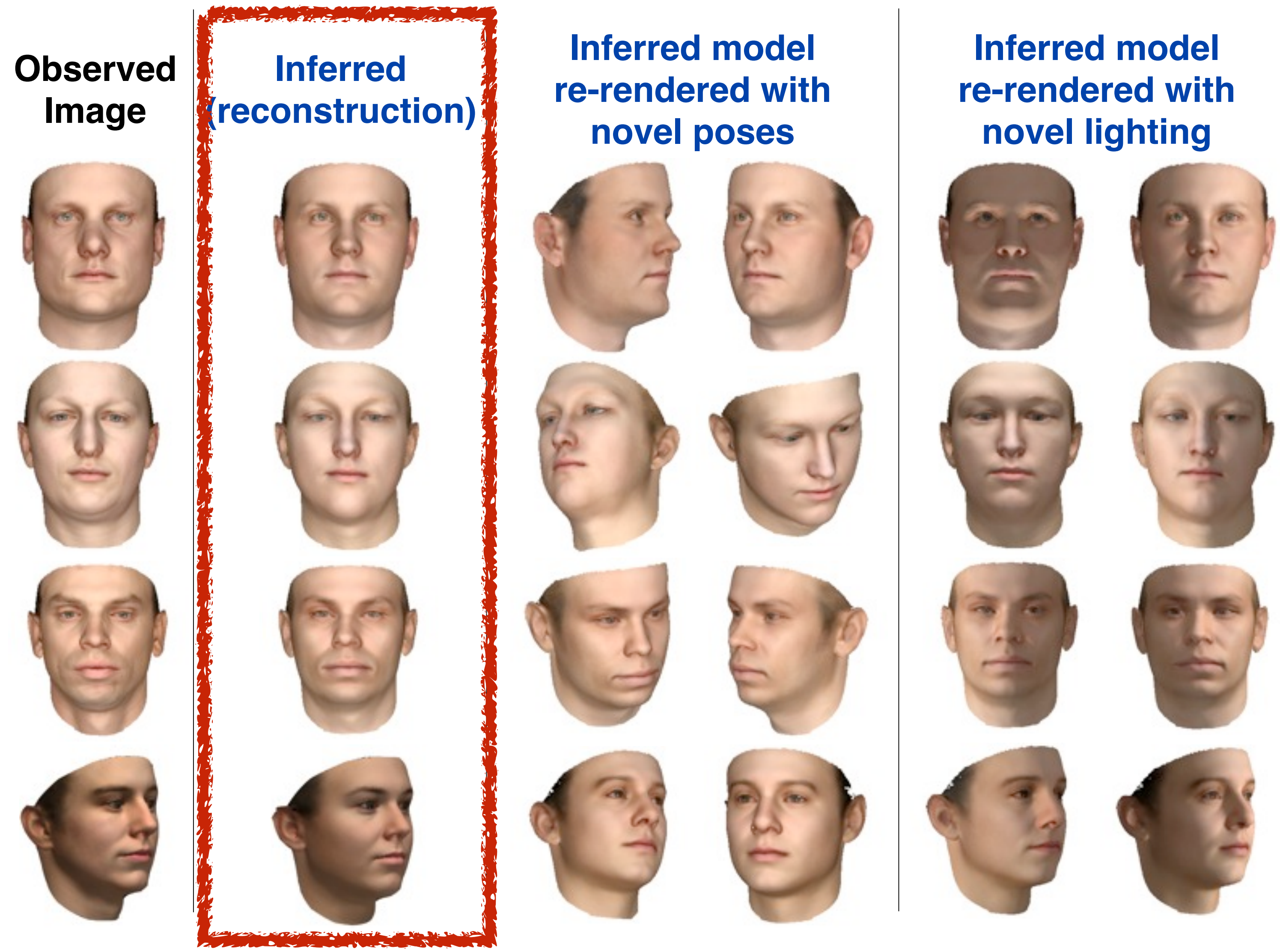


Transformed 3D models

Kulkarni, Kohl, Tenenvaum, Mansinghka [CVPR'15]

Th... ccess stories: 2) inverse graphics

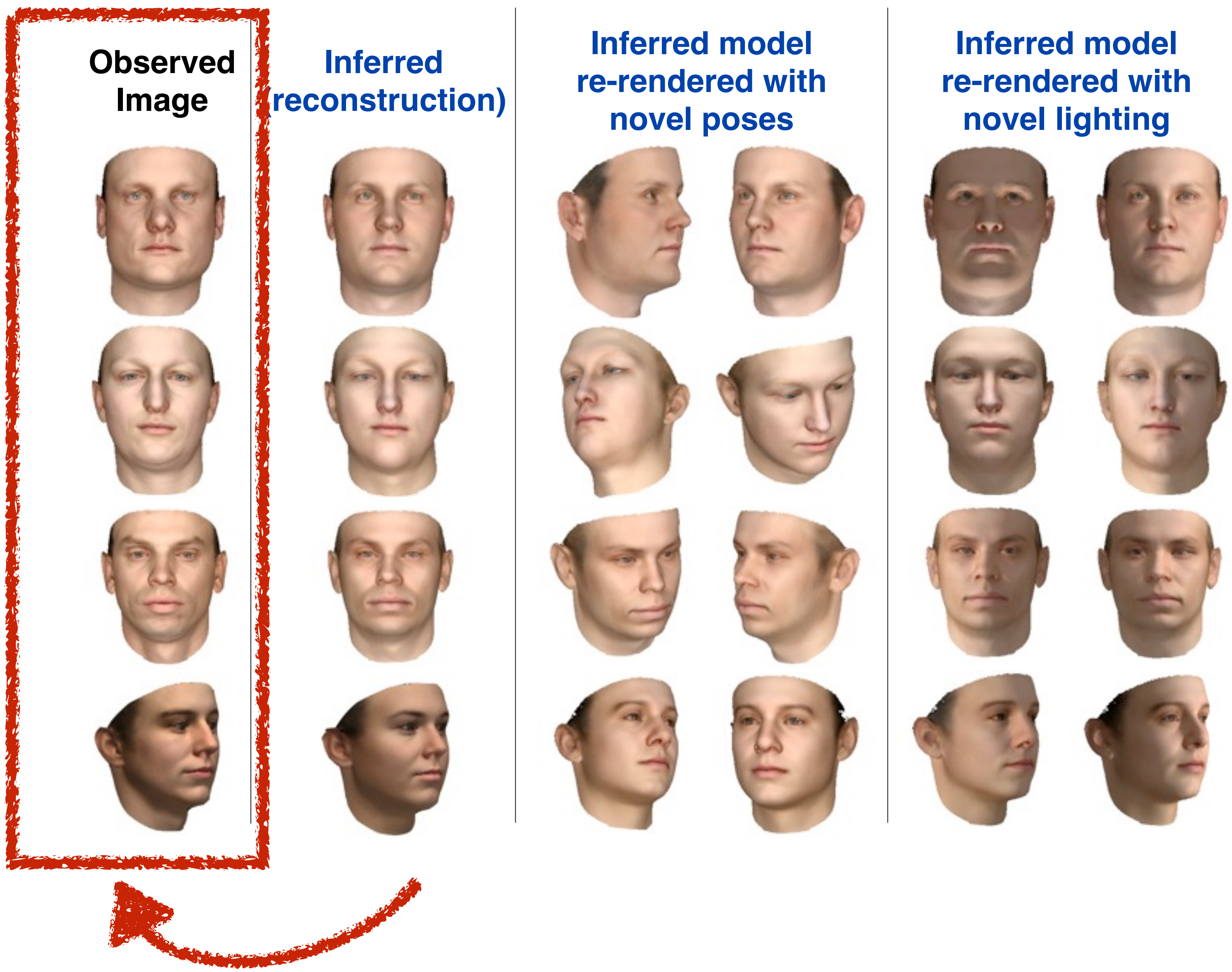
1. Sample a 3D model.



Kulkarni, Kohl, Tenenvaum, Mansinghka [CVPR'15]

ccess stories:
rse graphics

1. Sample a 3D model.
2. Generate an image.



Kulkarni, Kohl, Tenenvaum, Mansinghka [CVPR'15]

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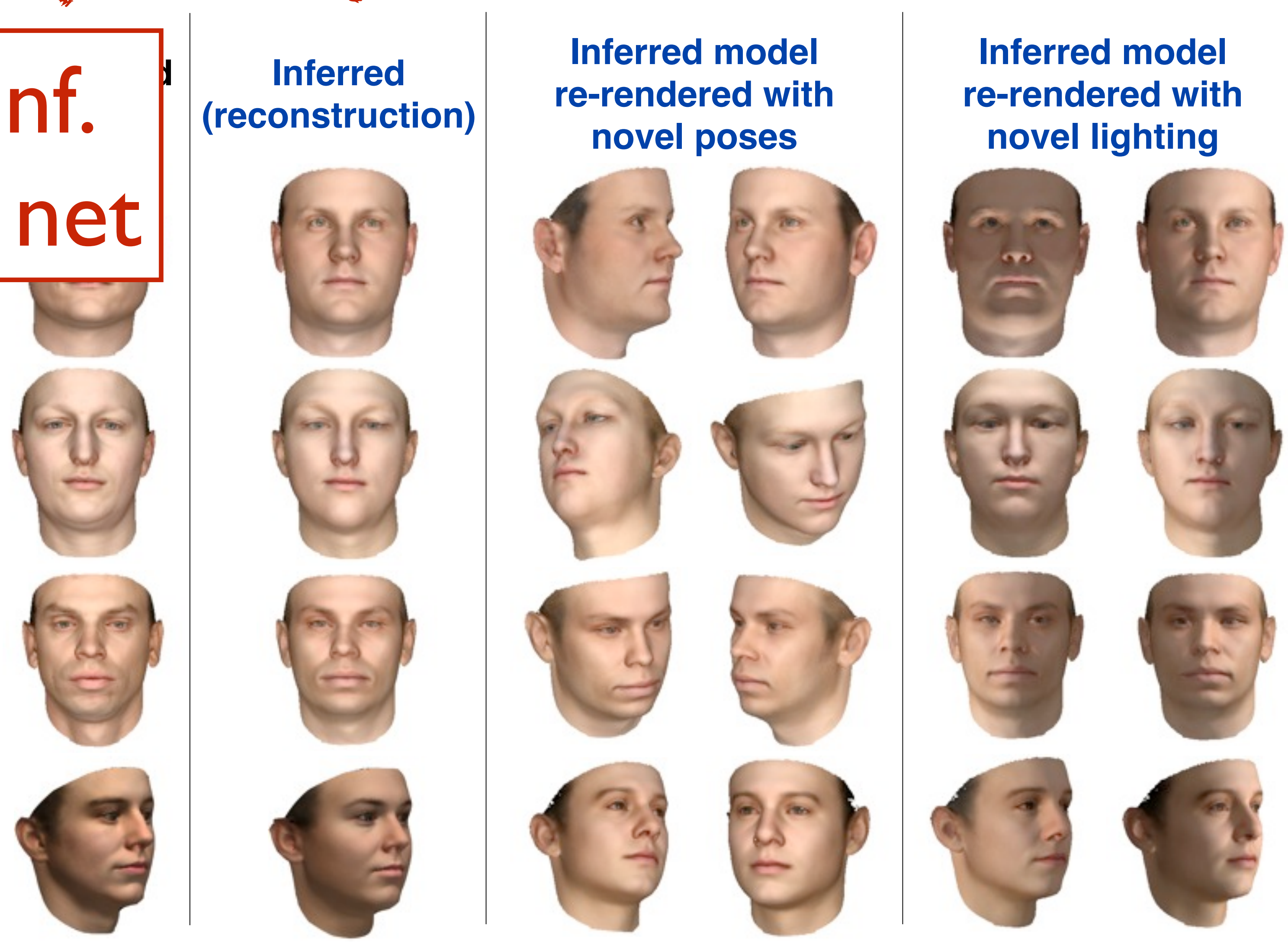
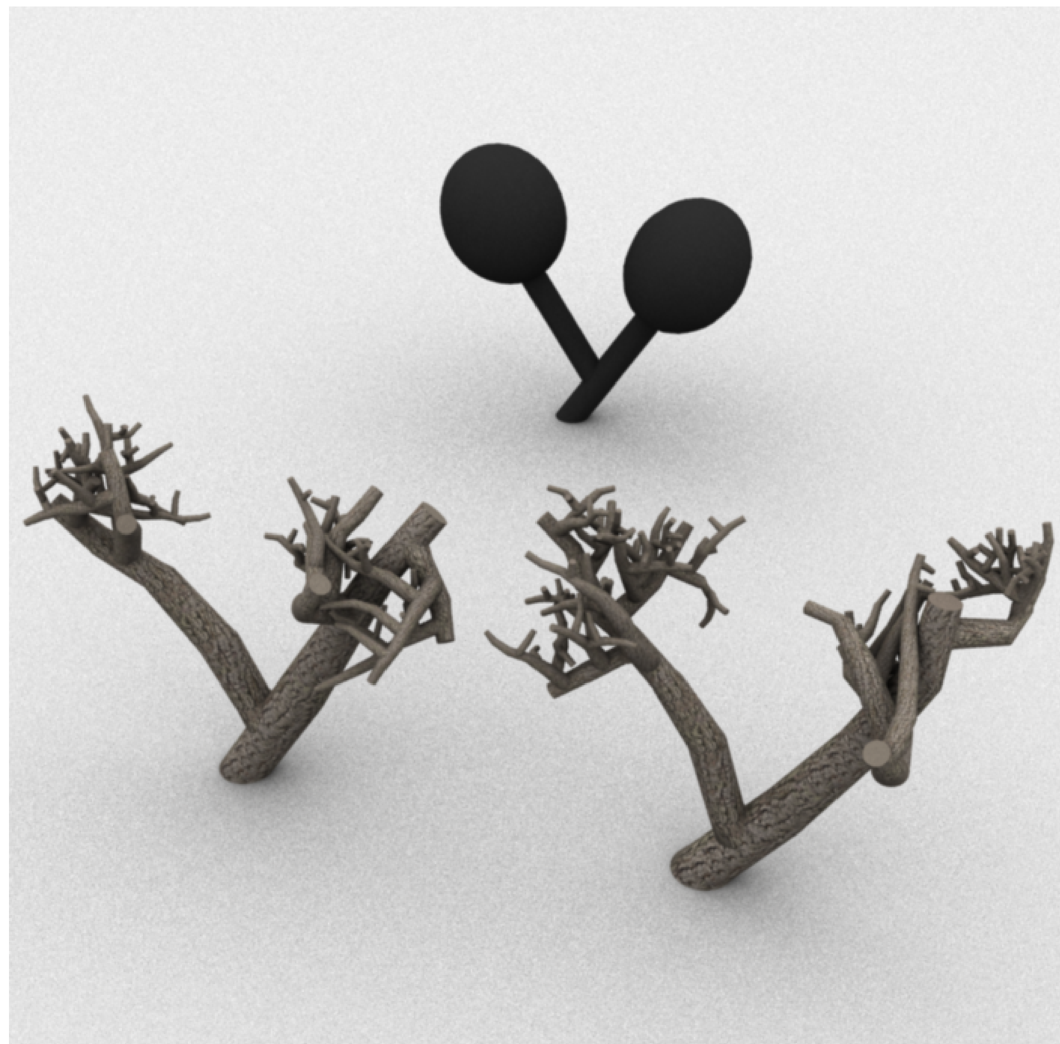
Posterior inf. with neural net



Kulkarni, Kohl, Tenenvaum, Mansinghka [CVPR'15]

Three success stories:
3) procedural modelling



Ritchie, Mildenhall, Goodman, Hanrahan [SIGGRAPH'15]

Three success stories:
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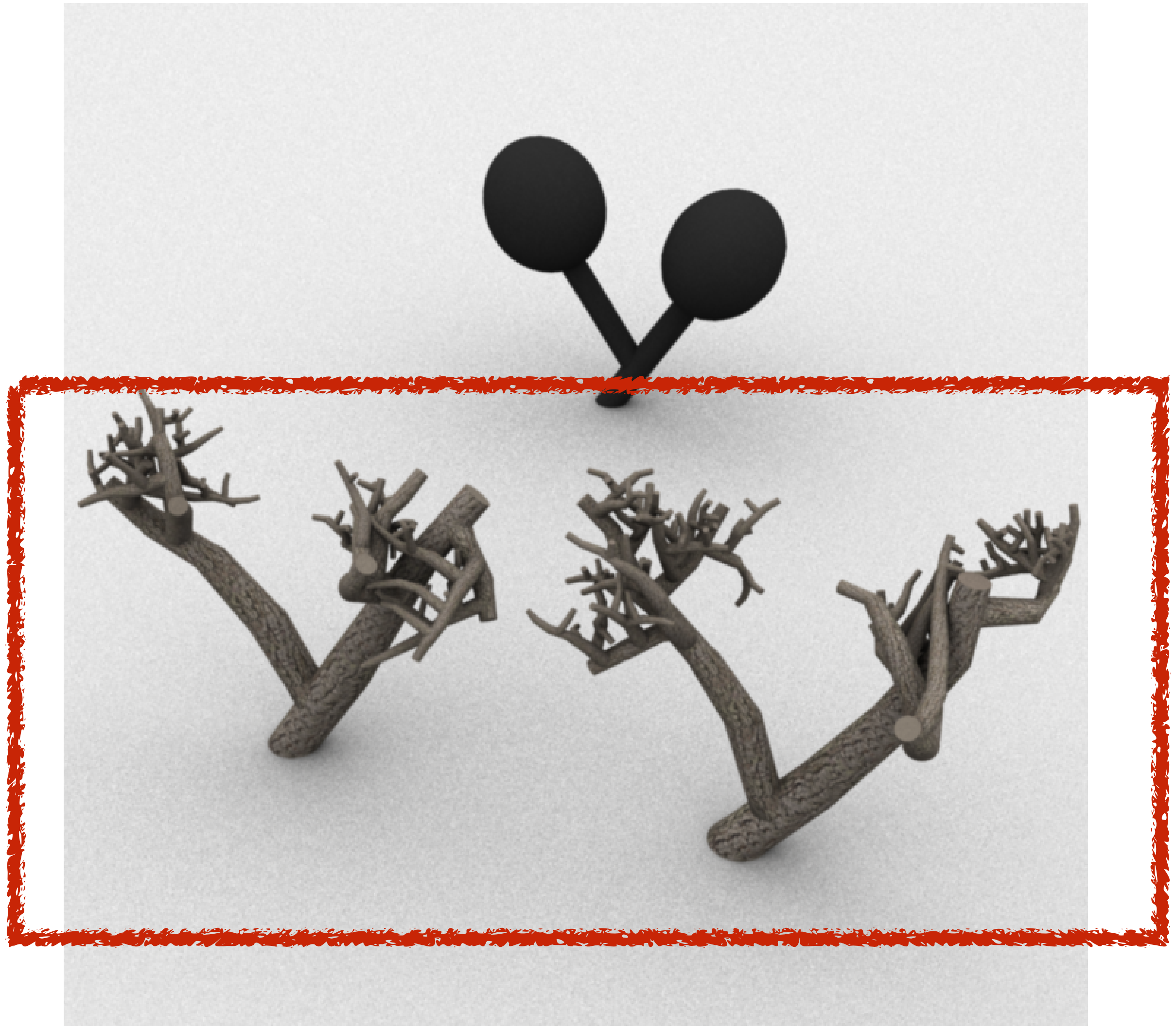
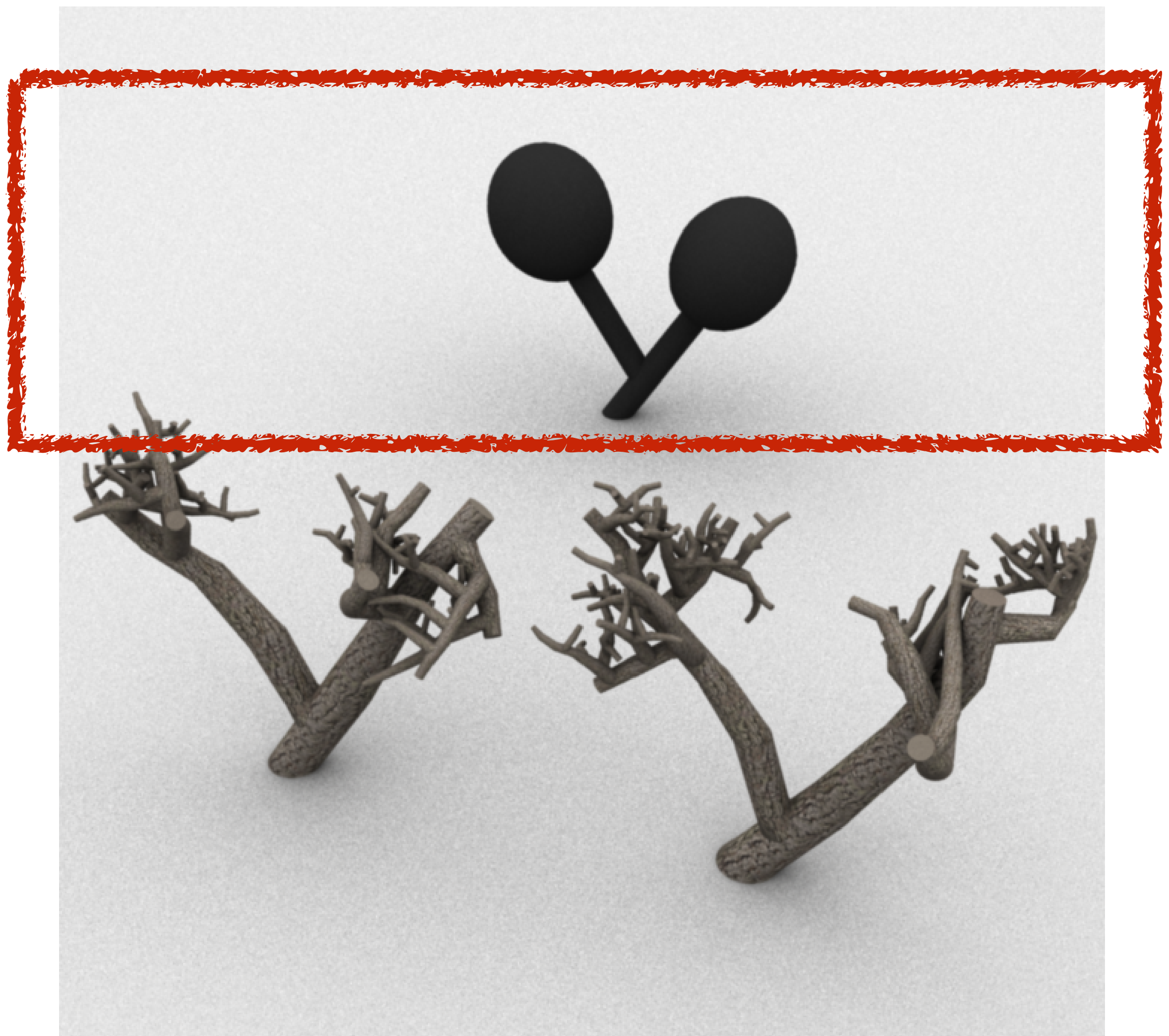


1. Sample a 3D object.

Ritchie, Mildenhall, Goodman, Hanrahan [SIGGRAPH'15]

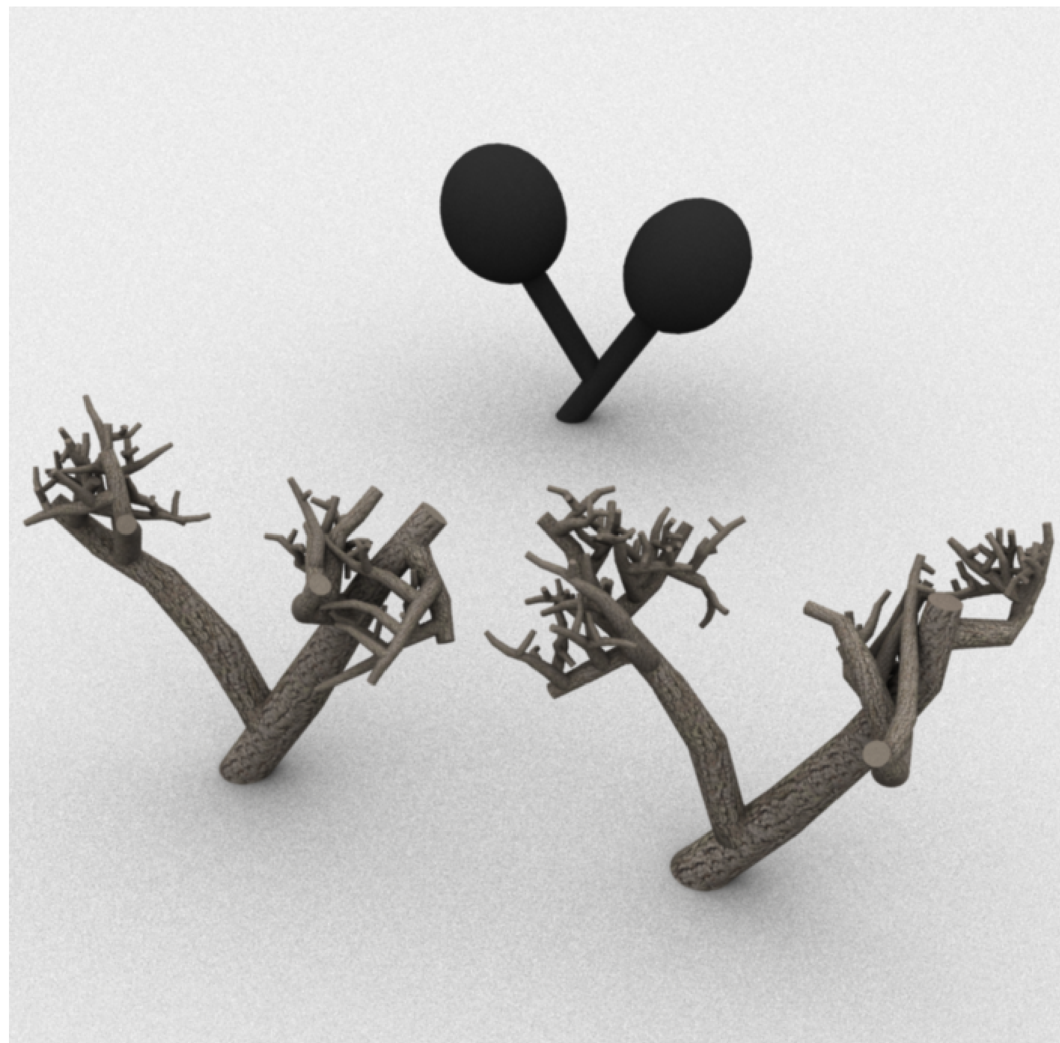
Three success stories: 3) procedural modelling



1. Sample a 3D object.
2. Score the object.

Ritchie, Mildenhall, Goodman, Hanrahan [SIGGRAPH'15]

Three success stories:
3) procedural modelling



1. Sample a 3D object.
2. Score the object.

Used stochastic future.

Ritchie, Mildenhall, Goodman, Hanrahan [SIGGRAPH'15]

Three suc

Asynchronous function call via future

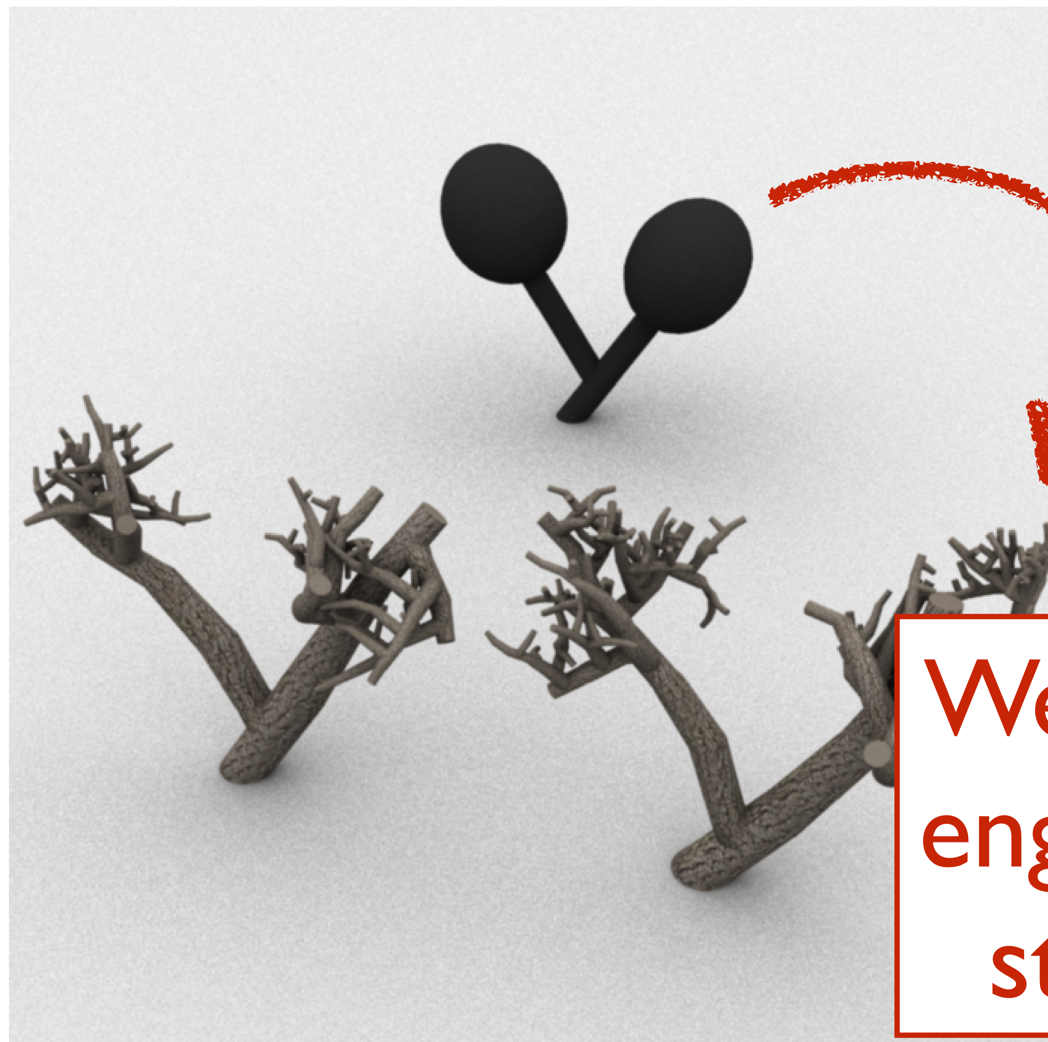
```
future.create(function(i, frame, prev)
        if flip(T.branchProb(depth, i)) then
                -- Theta mean/variance based on avg weighted by
                local theta_mu, theta_sigma = T.estimateThetaD
                local theta = gaussian(theta_mu, theta_sigma)
                local maxbranchradius = 0.5*(nextframe.center
                local branchradius = math.min(uniform(0.9, 1)
                local bframe, prev = T.branchFrame(splitFrame,
                branch(bframe, depth+1, prev)
        end
```

1. Sample a 3D object.
2. Score the object.

Used stochastic future.

Ritchie, Mildenhall, Goodman, Hanrahan [SIGGRAPH'15]

Three success stories:
3) procedural modelling



WebPPL's inference engine that exploits stochastic future

1. Sample a 3D object.
2. Score the object.

Used stochastic future.

Ritchie, Mildenhall, Goodman, Hanrahan [SIGGRAPH'15]

Techniques used

- Changepoints: CPS transformation and new foundation of probability theory.
- Captcha and inverse graphics: neural nets and inference amortisation.
- Procedural modelling: sequential Monte Carlo algorithms and stochastic future.

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Prog. Languages,

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Prog. Languages, Machine Learning,

Techniques used

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- Captcha and inverse graphics: neural nets and inference amortisation.
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Prog. Languages, Machine Learning, Probability Theory

Overview of the course

Objective

1. Learn how to write and reason about models in a prob. prog. language (PPL).
2. Learn results from ML/PL/prob. theory that are used for building effective PPLs.
3. Contribute to probabilistic programming.

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1. Learn how to write and reason about models in a prob. prog. language (PPL).
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3. Contribute to probabilistic programming.

Group project by a group of 1-3 students.

Webpage

https://github.com/hongseok-yang/probprog20

All the important announcements will be made in this webpage.

Evaluation

- 3-5 homework exercises (20%).
- Group project (40%).
- Final exam (40%).

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1-3 students form a group.

New cool application of a PPL.

Tasks:

- Project.
- 2 (likely online) presentations (topic - 27 Apr, result - 17/22/24 June).
- Report. 2 pages not including bibliography.

Really important announcement

Form a group and inform me and TAs by the midnight of 30 March (Monday).

Somewhat important announcement

- Lecturer: Prof Hongseok Yang

  email: hongseok00@gmail.com

- TAs: Gwonsoo Che, Daeseok Lee

  email: Gwonsoo.che@gmail.com

  email: dsleemaths@gmail.com

- Install Anglican. Try the changepoint example. Get hints from the webpage.

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