

Informational Analysis of Invasion Percolation Model of Hydraulic Fracturing

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May 31, 2013

① Hydraulic Fracturing

② Simple Model

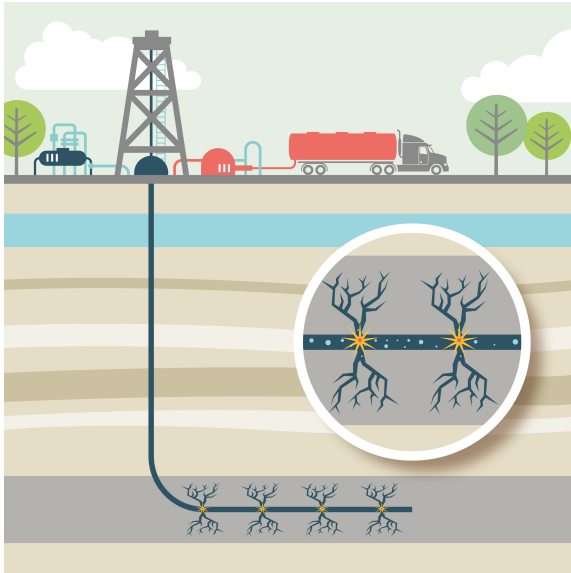
③ Invasion Percolation

④ Bursts

⑤ Information Theory

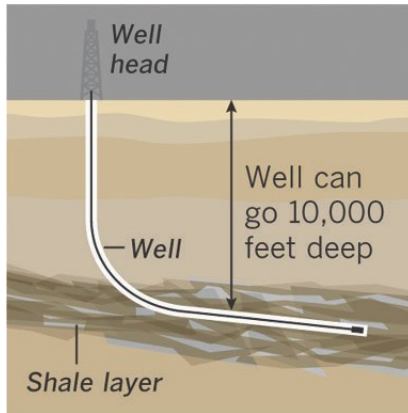
⑥ Tokunaga Branching

Hydraulic Fracturing



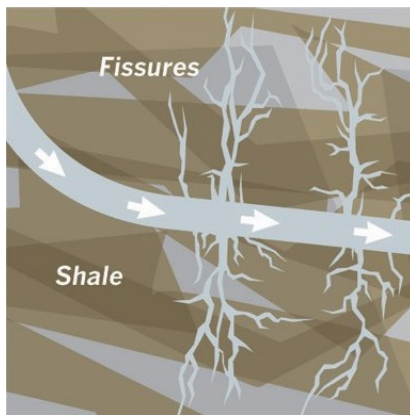
Hydraulic Fracturing

Step 1: Drill a well



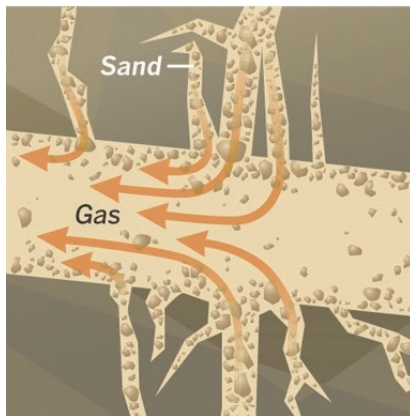
Hydraulic Fracturing

Step 2: Inject fluid to generate fractures

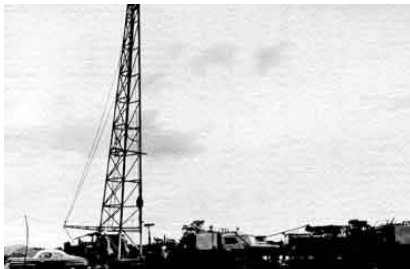


Hydraulic Fracturing

Step 3: Sand “props” fractures open allowing gas/oil to flow out

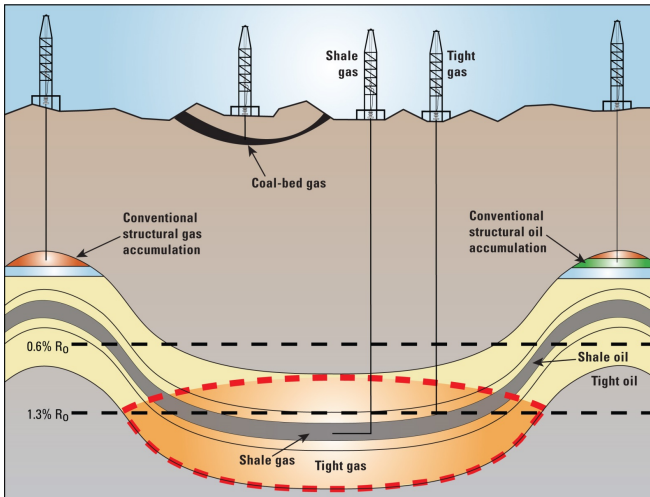


Hydraulic Fracturing



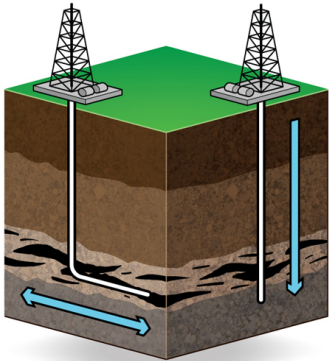
Halliburton in the late 1940's

Hydraulic Fracturing



USGS Potential Gas Committee (2011)

Hydraulic Fracturing

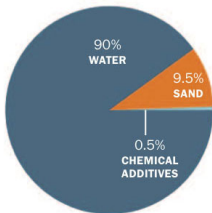


Horizontal Drilling



“Slickwater”

Hydraulic Fracturing



Compound	Purpose	Common application
Acids	Helps dissolve minerals and initiate fissure in rock (pre-fracture)	Swimming pool cleaner
Sodium Chloride	Allows a delayed breakdown of the gel polymer chains	Table salt
Polyacrylamide	Minimizes the friction between fluid and pipe	Water treatment, soil conditioner
Ethylene Glycol	Prevents scale deposits in the pipe	Automotive anti-freeze, deicing agent, household cleaners
Borate Salts	Maintains fluid viscosity as temperature increases	Laundry detergent, hand soap, cosmetics
Sodium/Potassium Carbonate	Maintains effectiveness of other components, such as crosslinkers	Washing soda, detergent, soap, water softener, glass, ceramics
Glutaraldehyde	Eliminates bacteria in the water	Disinfectant, sterilization of medical and dental equipment
Guar Gum	Thickens the water to suspend the sand	Thickener in cosmetics, baked goods, ice cream, toothpaste, sauces
Citric Acid	Prevents precipitation of metal oxides	Food additive; food and beverages; lemon juice
Isopropanol	Used to increase the viscosity of the fracture fluid	Glass cleaner, antiperspirant, hair coloring



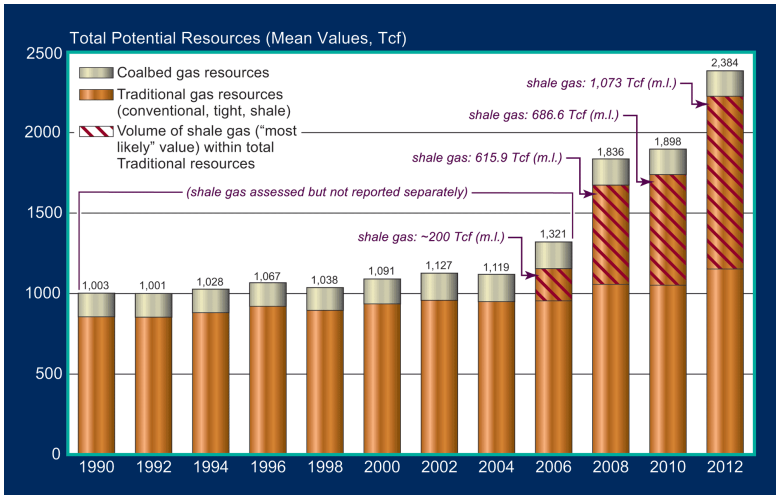
Source: DOE, GWPC: Modern Gas Shale Development in the United States: A Primer (2009).

Hydraulic Fracturing



“Super Fracking” Today

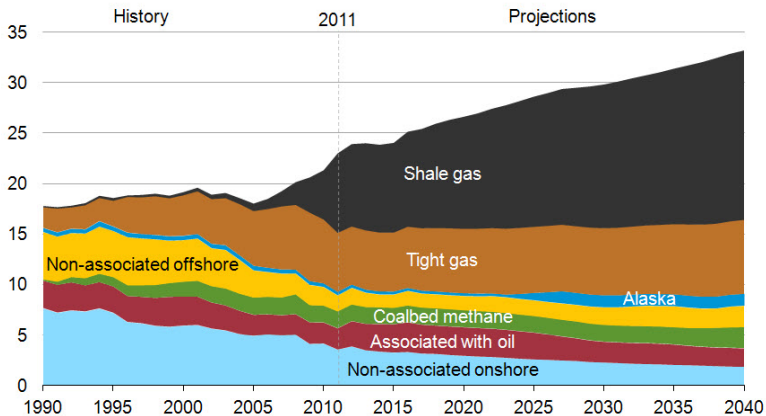
Hydraulic Fracturing



Potential Gas Committee (2011)

Hydraulic Fracturing

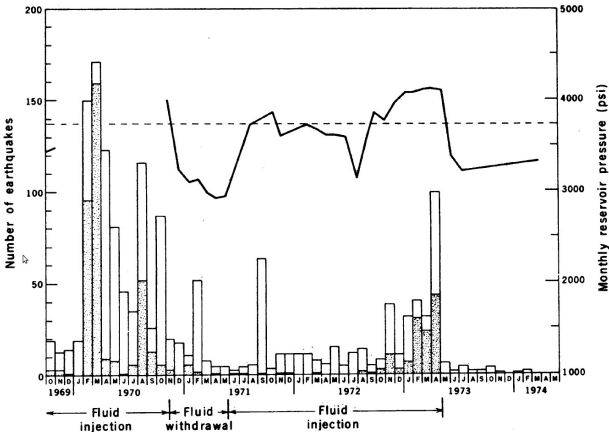
U.S. dry natural gas production trillion cubic feet



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2013 Early Release*

Hydraulic Fracturing

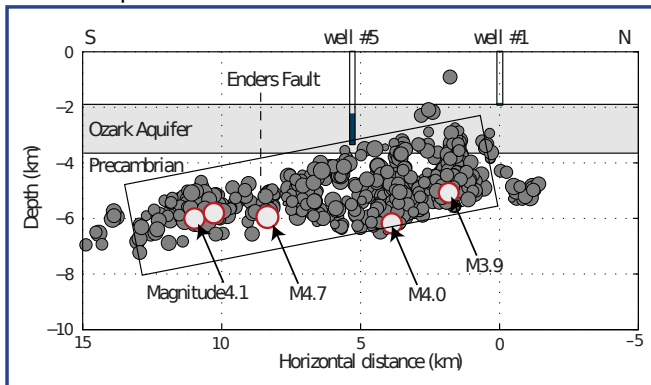
Problem: Earthquakes known since 1976



C. B. Raleigh et al. Science 191(4233), 66-75

Hydraulic Fracturing

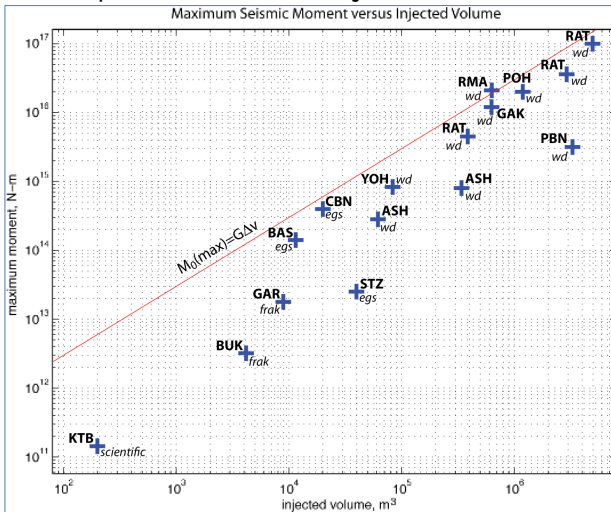
Problem: Earthquakes



R. A. Kerr. Science 335(6075), 1436-1437

Hydraulic Fracturing

Problem: Earthquakes from fluid reinjection



Art McGarr (USGS)

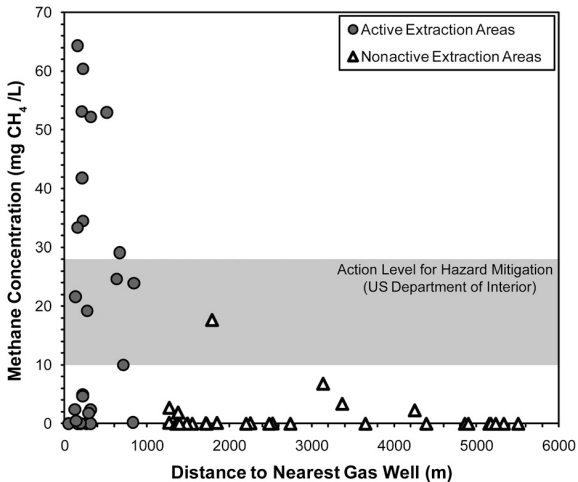
Hydraulic Fracturing

Problem: Contaminated Drinking Water



Hydraulic Fracturing

Problem: Contaminated Drinking Water



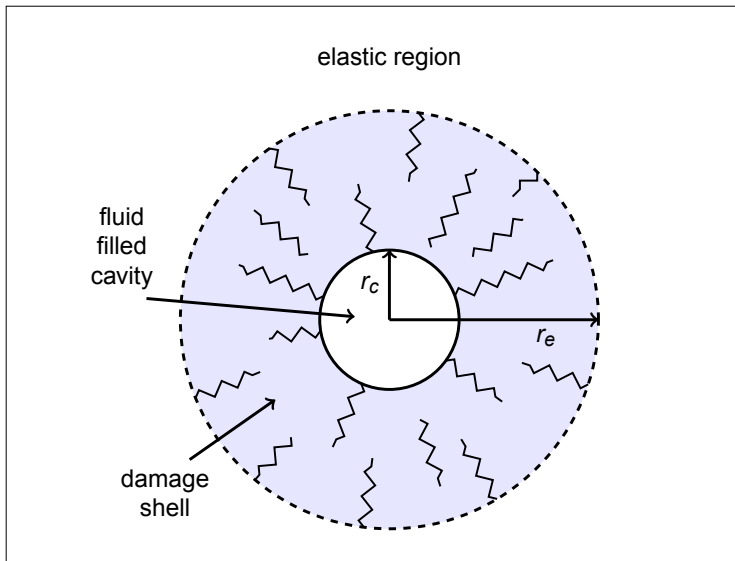
Osborn et al. PNAS, 108(20), 8172-8176.

Hydraulic Fracturing

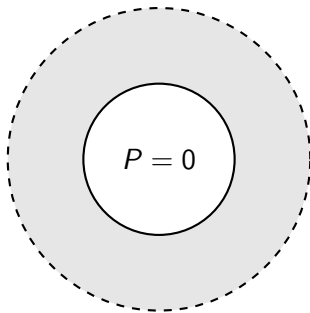
Summary

- Main source of natural gas for the next 40 years
- Causes earthquakes
- May contaminate drinking water

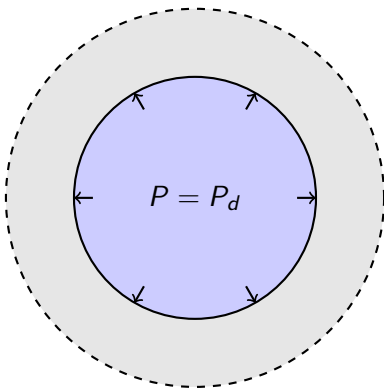
Simple Model



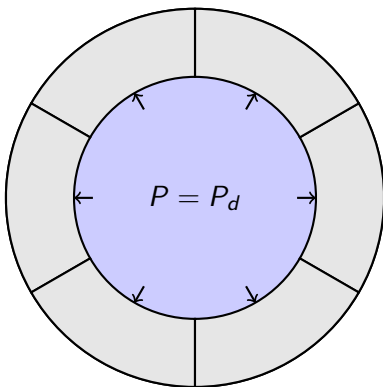
Simple Model



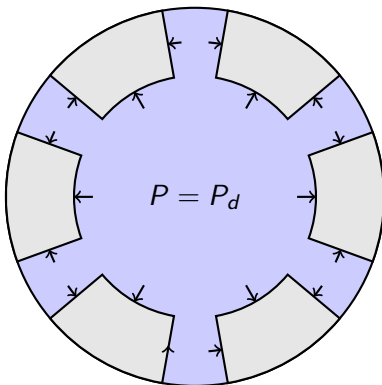
Simple Model



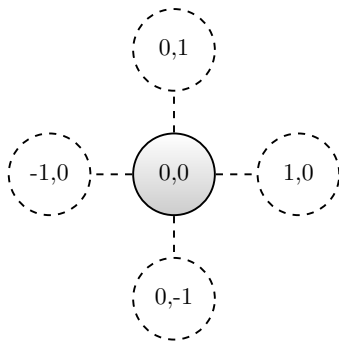
Simple Model



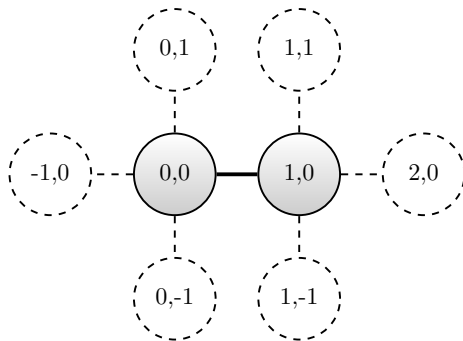
Simple Model



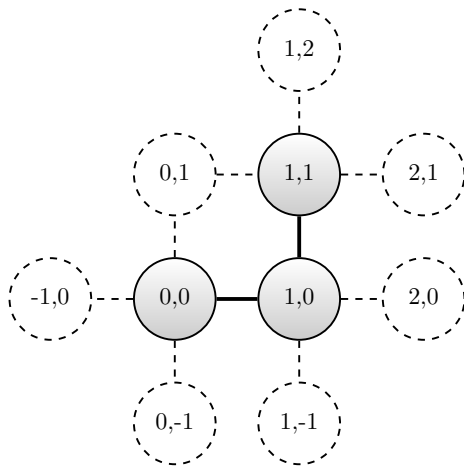
Modified Invasion Percolation



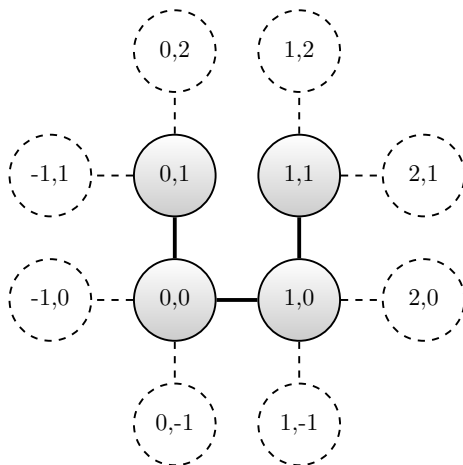
Modified Invasion Percolation



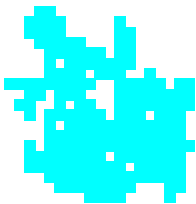
Modified Invasion Percolation



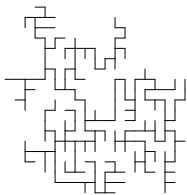
Modified Invasion Percolation



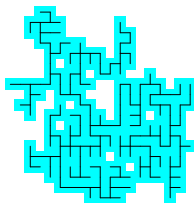
Modified Invasion Percolation



Sites



Bonds

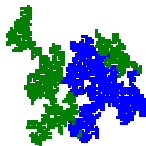


Cluster

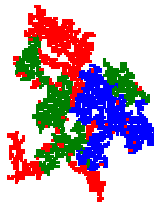
Modified Invasion Percolation



$t = 1000$

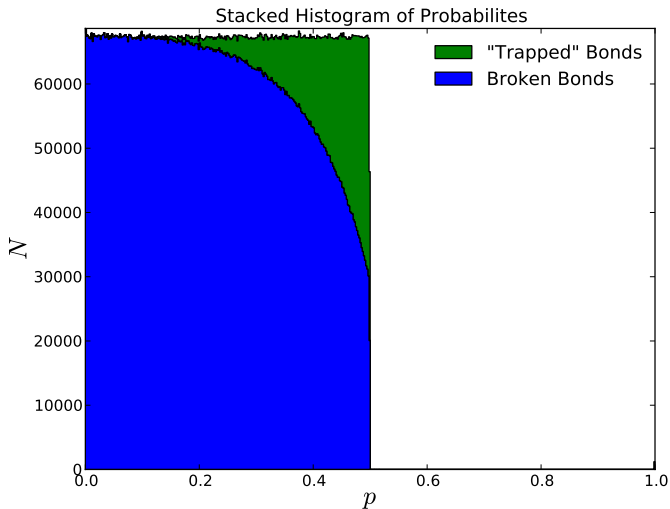


$t = 2000$

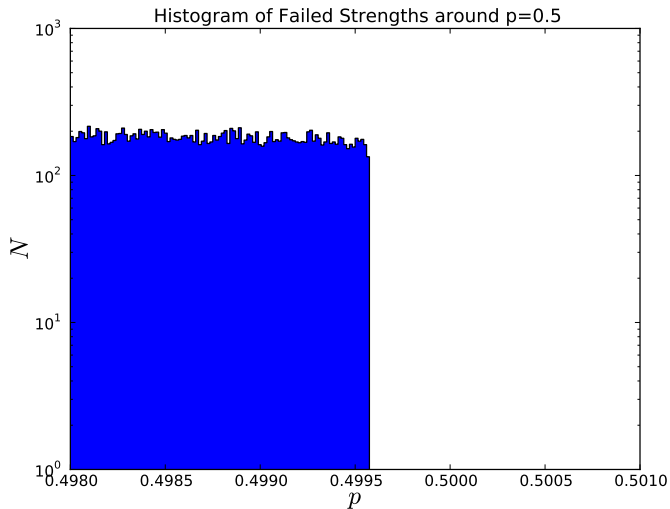


$t = 3000$

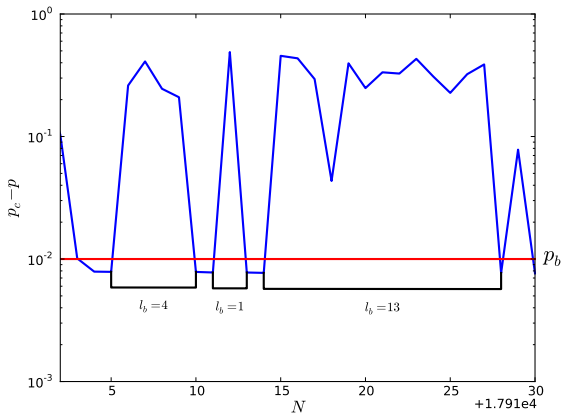
Modified Invasion Percolation



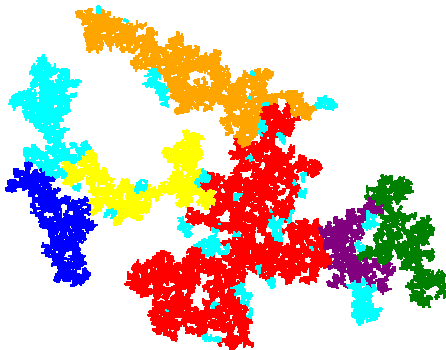
Modified Invasion Percolation



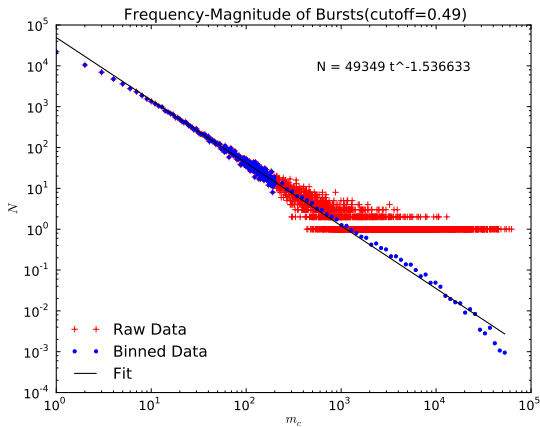
Waterlevel Bursts



Waterlevel Bursts



Waterlevel Bursts

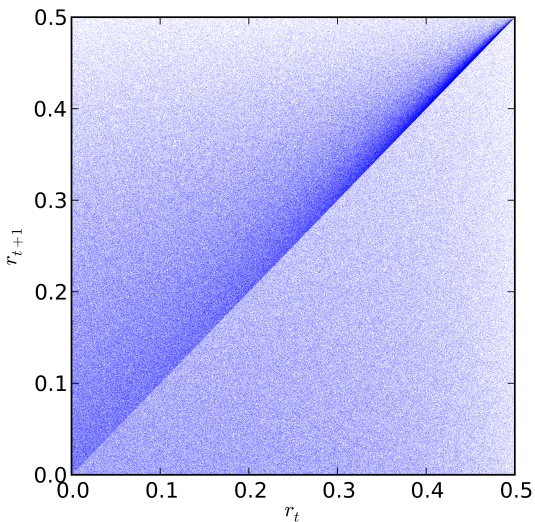


Information Theory Measures

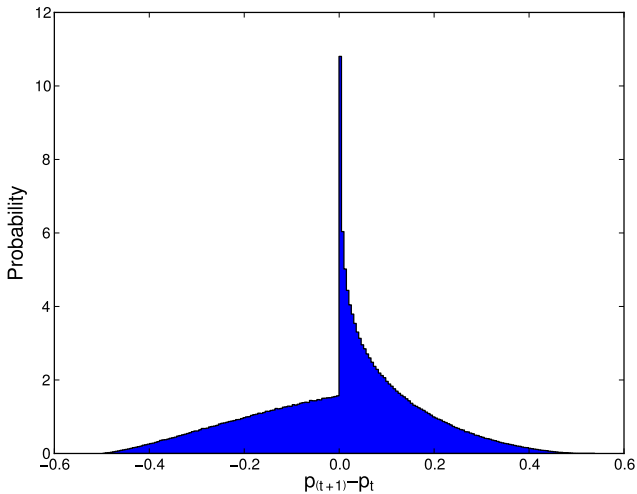
Reduce dimensionality by looking time-series of strengths

$$\cdots p_{-2}, p_{-1}, p_0, p_1, p_2 \cdots$$

Information Theory Measures



Information Theory Measures



Information Theory Measures

Encodings

Strength encoding:

$$p_t < p_{t+1} \rightarrow 1$$

$$p_t > p_{t+1} \rightarrow 0$$

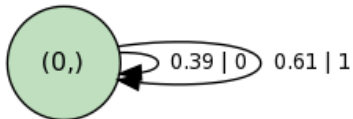
Temporal encoding:

$$s_t \text{ n.n. } s_{t+1} \rightarrow 1$$

$$s_t \overline{\text{n.n.}} s_{t+1} \rightarrow 0$$

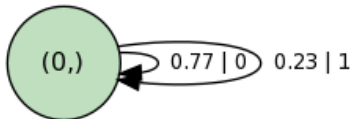
Information Theory Measures

Bayesian Inference: Strength Encoding



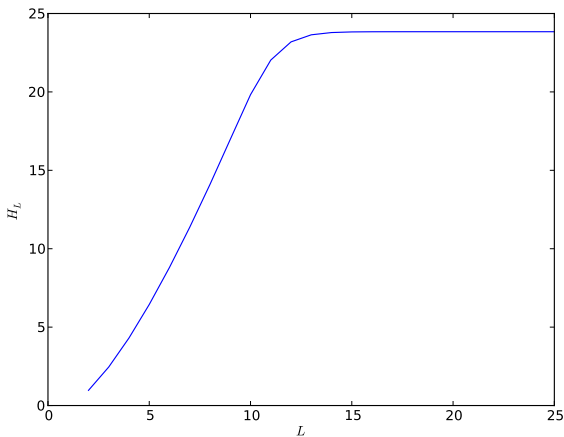
Information Theory Measures

Bayesian Inference: Spatial Encoding

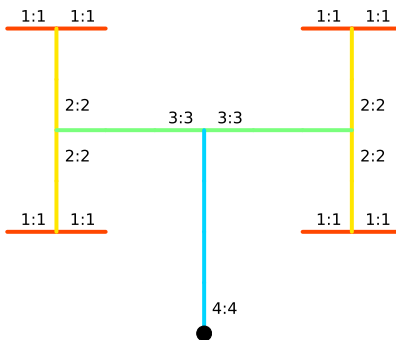


Information Theory Measures

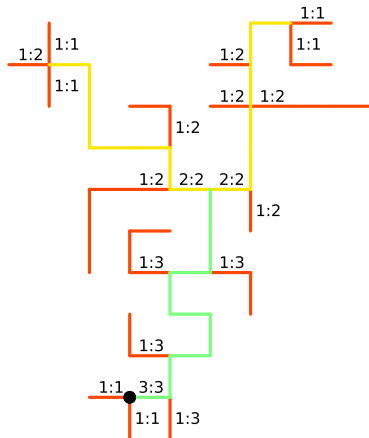
Permutation Entropy



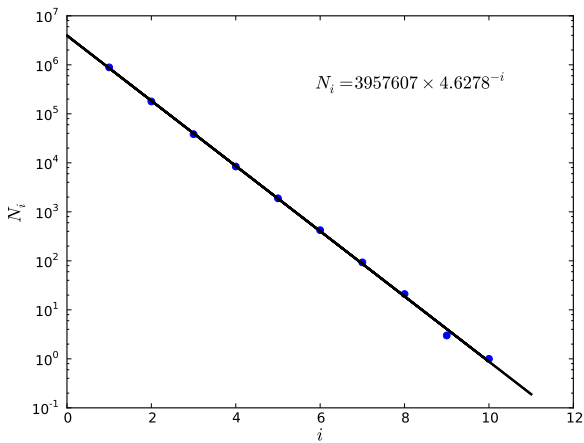
Tokunaga Branching



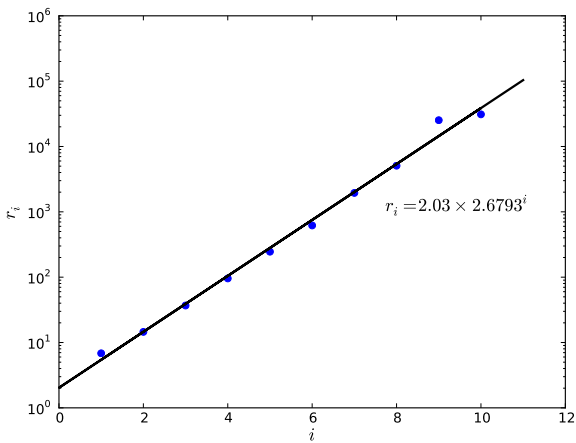
Tokunaga Branching



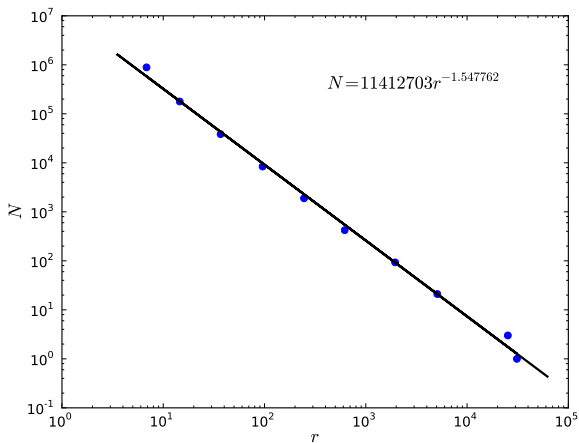
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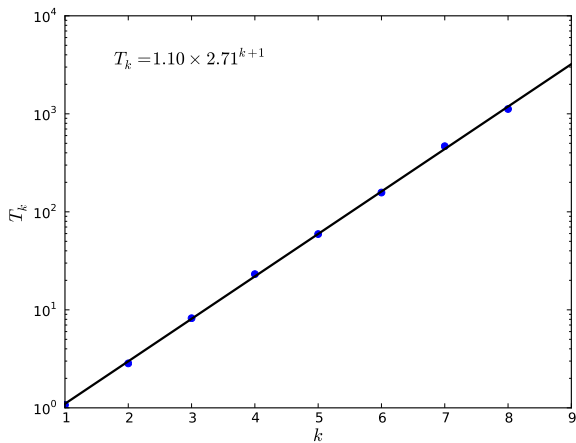
Tokunaga Branching



Tokunaga Branching



Tokunaga Branching



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- Funded by
US Department of Energy to UC Davis,
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