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Exponential Decay in Probabilistic Trust Models

Mogens Nielsen's 60th Fest

Aarhus, 4/10/09

To your sharpness of mind and kindness of heart

Vladimiro Sassone

I dag er det Mogens' fødselsdag

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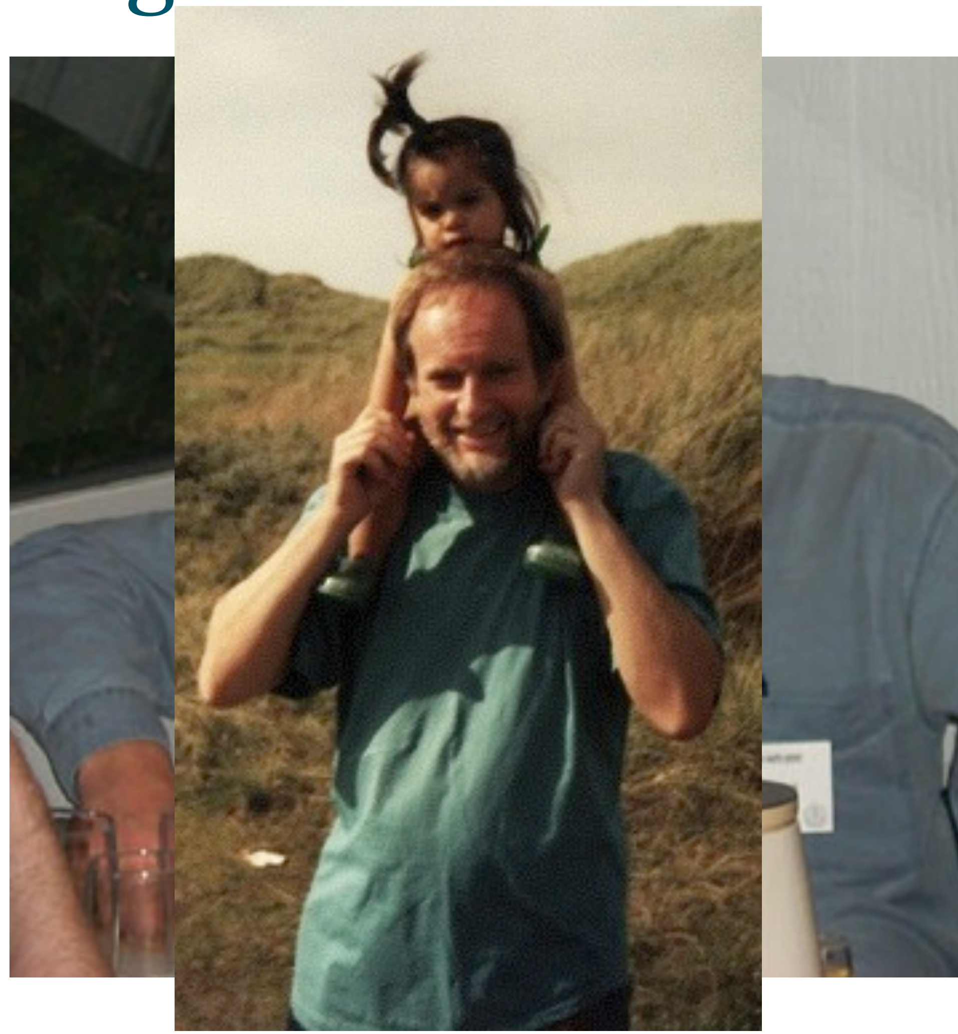

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Trust in UbiCom

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- Features of Ubiquitous Computing like *scalability*, *mobility*, and *incomplete information* deeply affect security requirements.

- One of the proposed approaches is to use a notion of *computational trust*, resembling the concept of trust among human beings.

Probabilistic Trust

- *Probabilistic models* are used to evaluate trust.
- A probabilistic model assigns a degree of confidence to a principal's ability to predict another principal's behaviour.
- Eg, the behaviour of a principal *A* may be defined as the probability that interaction with *A* yields a certain outcome (eg, success or failure).

Beta Trust Model

- The outcome of an interaction between a principal a *and* a partner b is either *successful* or *unsuccessful:*

$$o \in \{Succ,\ Fail\}$$

- The probability that a partner b interacts successfully with a is governed by the parameter θ where

$$\theta = \Pr(o = Succ)$$

Beta Trust Model

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- The behaviour of the partner b represented by θ is assumed to be fixed over time.

- The estimated probability of success, $B(Succ\ |o)$, at time t is the expected value of θ *given the sequence of outcomes* $o = \{o_0, o_1, \ldots, o_t\}$

$$B(\,Succ \mid o) = E[\,\theta \mid o\,]$$

Beta Trust Model

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Using Bayesian inference to learn the parameter θ from observations o.

The random variable θ follows Beta distribution function, and therefore

$$B(\,Succ \mid o) = E[\,\theta \mid o\,] = \frac{m(o)+1}{m(o)+n(o)+2}$$

where $m(o)$ is the number of successful interactions in o and $n(o)$ that of unsuccessful ones in o.

Trust Inference Process

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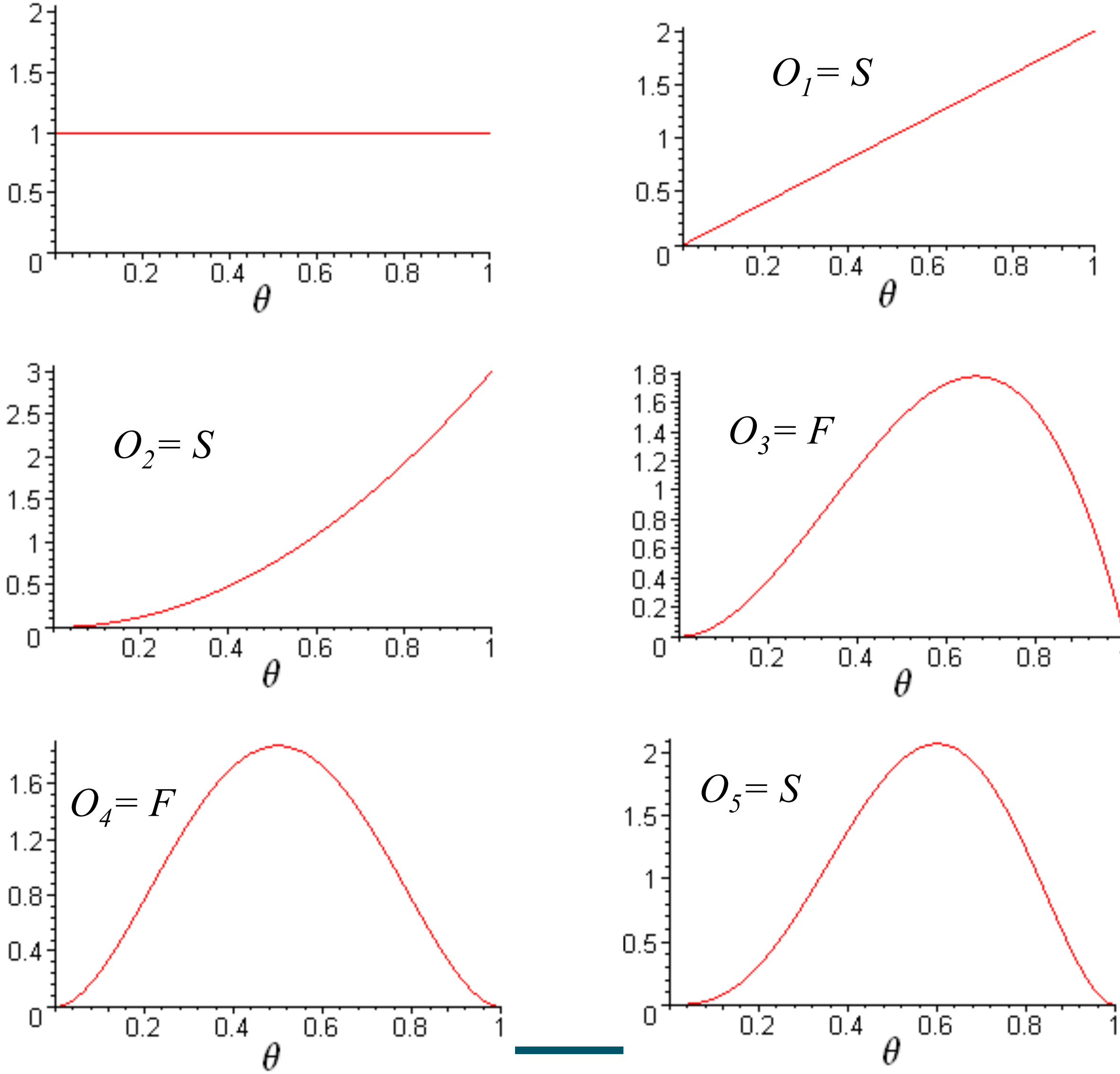

Trust Inference Process

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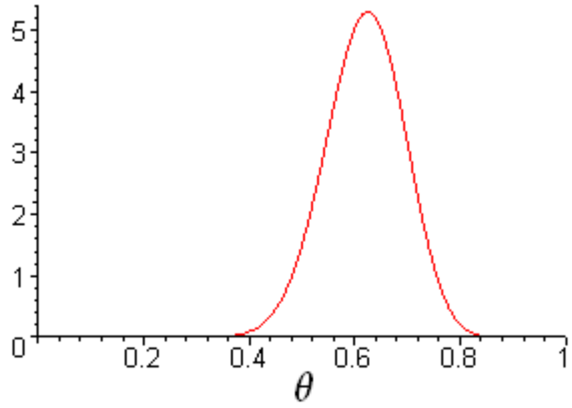
The distribution of θ after 40 interactions
25 Successful and 15 Failed



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Limitation of the Beta model

- The assumption that a principal behaviour is fixed is not always realistic:
- The behaviour of a principal may depend on its internal state which may change over time.

Modelling Dynamic Behaviour

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- Modelling static behaviour as a probability distribution over outcomes leads to modelling the dynamic behaviour by a *Hidden Markov Model (HMM).*

- A single state in an HMM models the system behaviour at a particular time.

Hidden Markov Model:

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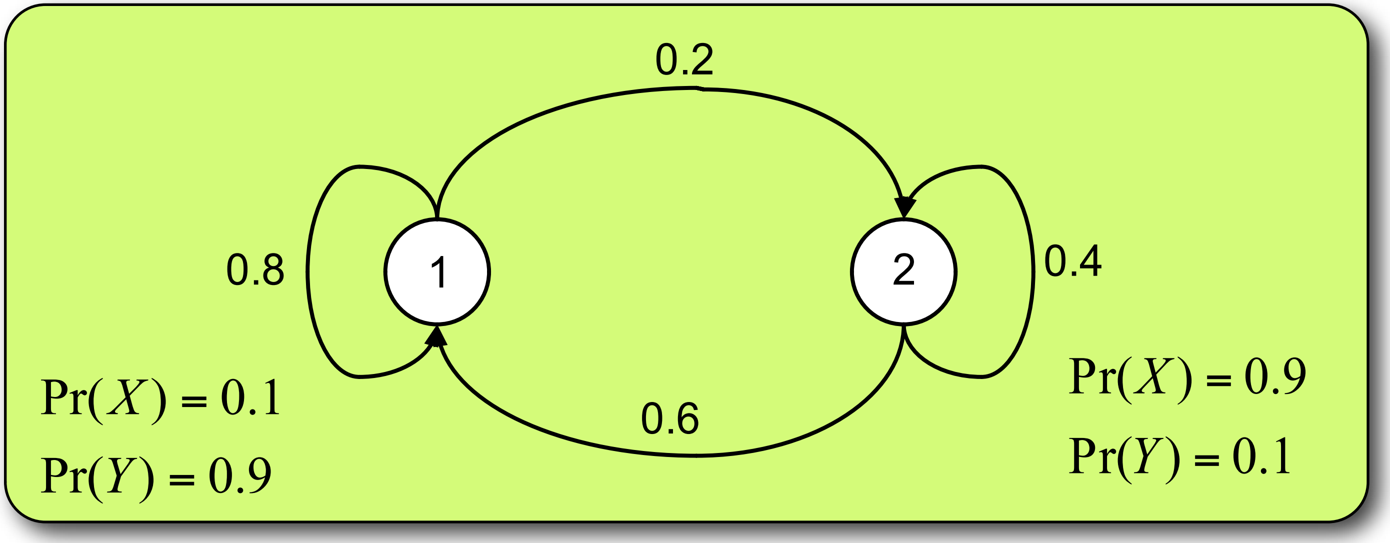

$$S = \{1,2\}$$

$$V = \{X, Y\}$$

$$A = \begin{bmatrix} 0.8 & 0.2 \\ 0.6 & 0.4 \end{bmatrix} \qquad B = \begin{bmatrix} 0.9 & 0.1 \\ 0.1 & 0.9 \end{bmatrix}$$

Beta Trust Model with Decay

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- The probability distribution over outcomes changes over time.
- Old observations are given less weight (decayed) than more recent observations.
- Weights of observations are controlled by the decay factor r.

Beta Trust Model with Decay

Given a decay factor $0 \leq r < 1$ and an observation sequence $o=\{o_L,\ldots,o_1,o_0\}$, where o_0 is the last outcome, o_1 is the previous outcome, and so on, then

$$B_r(Succ|O) = \frac{m_r(O)+1}{m_r(O)+n_r(O)+2} \quad , \quad B_r(Fail|O) = \frac{n_r(O)+1}{m_r(O)+n_r(O)+2}$$

Where

$$m_r(O) = \sum_{i=0}^{L} r^i \delta_i(Succ) \quad , \quad n_r(O) = \sum_{i=0}^{L} r^i \delta_i(Fail)$$

And

$$\delta_i(Succ) = \begin{cases} 1 & \text{if } o_i = Succ \\ 0 & \text{otherwise} \end{cases} \quad , \quad \delta_i(Fail) = \begin{cases} 1 & \text{if } o_i = Fail \\ 0 & \text{otherwise} \end{cases}$$

How good is the model ?

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- Given a dynamic system modelled by an HMM λ we define Beta estimation error as follows

$$\mathrm{Error}(\lambda, r) = E\left[\,(B(\,Succ \mid o) - \alpha)^2\,\right]$$

where r is the decay factor, and α is the real probability that next outcome is Success

System Stability

- *System stability* is the expected probability of the HMM remaining in the same state.

- Consider the system modelled by HMM:

$$A_\lambda = \begin{bmatrix} s & \frac{1-s}{3} & \frac{1-s}{3} & \frac{1-s}{3} \\ \frac{1-s}{3} & s & \frac{1-s}{3} & \frac{1-s}{3} \\ \frac{1-s}{3} & \frac{1-s}{3} & s & \frac{1-s}{3} \\ \frac{1-s}{3} & \frac{1-s}{3} & \frac{1-s}{3} & s \end{bmatrix} \qquad \Theta_\lambda = \begin{bmatrix} 1.0 \\ 0.7 \\ 0.3 \\ 0.0 \end{bmatrix}$$

Unstable System

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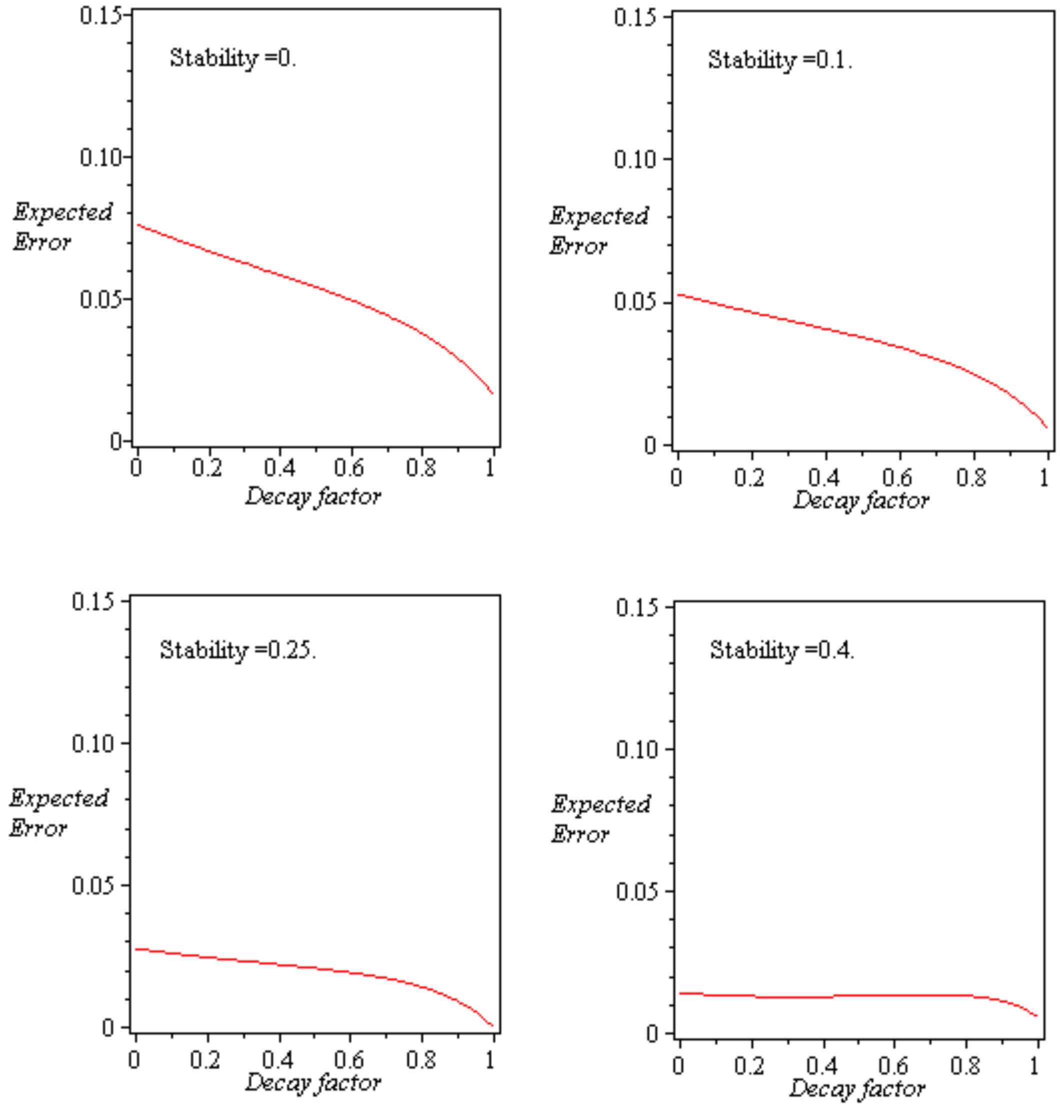

Stable System

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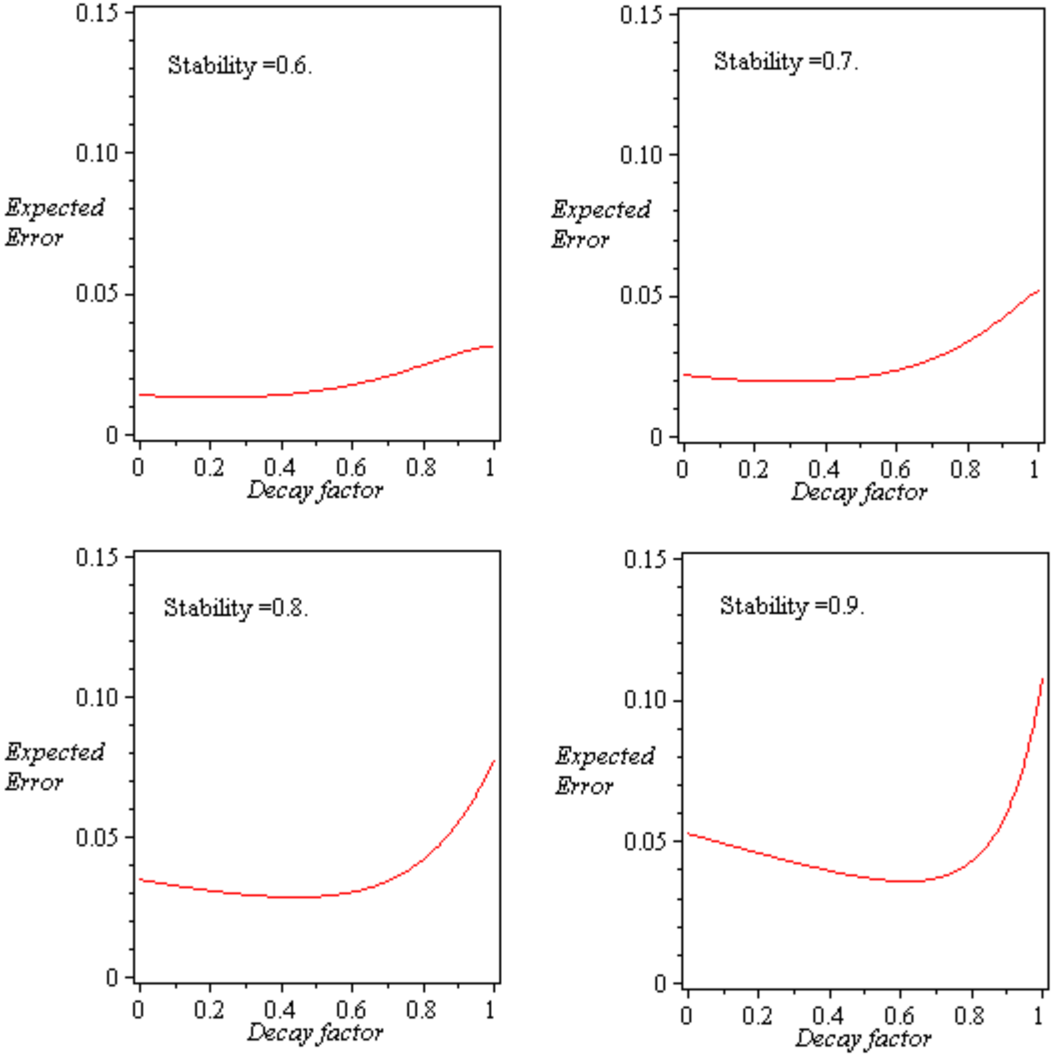

Very Stable System

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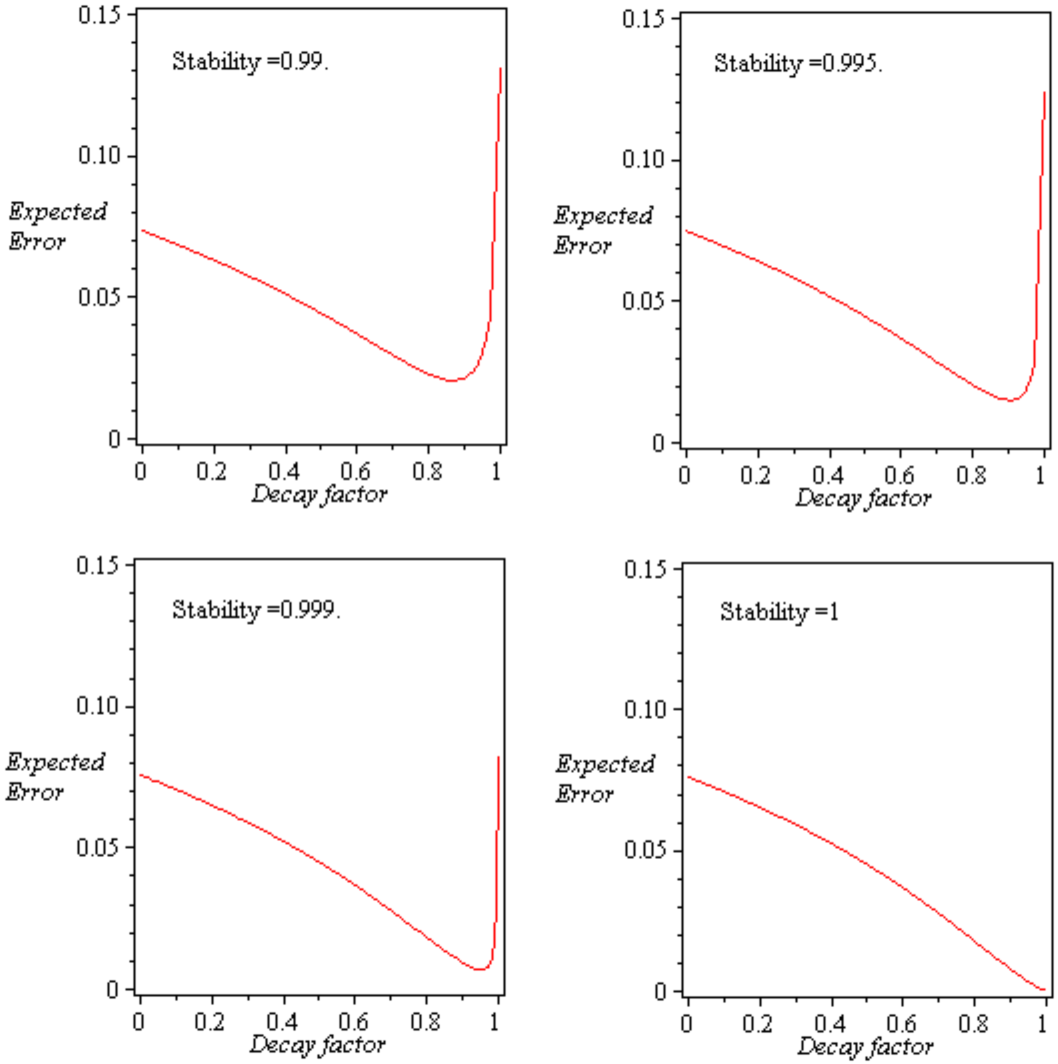

Conclusion

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- Traditional Beta trust models are unable of coping with dynamic behaviour systems.
- Using a decay scheme enhances Beta estimation in cases where the system is very stable.
- Beta estimation error is subject to choosing the optimal value of decay which depends on the system parameters.

Current and Future Work

- Investigate using HMM as a trust model instead of using existing Beta models [FAST 2009 with MN]

- Handling Reputation problems
  - Modelling reputation reports
  - Combining reputation reports to update trust
  - Evaluating confidence in the evaluated trust