Cultural Heritage Preservation using Smart Structural Health Monitoring

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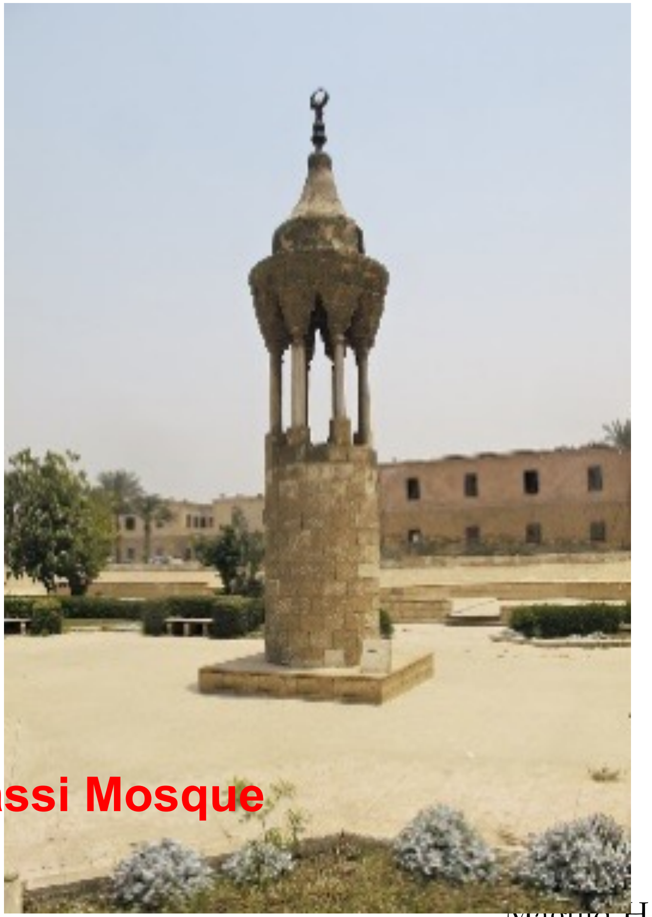
Outline

- Cultural Heritage
- Structural Health Monitoring
- Objective
- Smart Pattern Identification
  - ANN model
  - FIS model
- Reliability & Uncertainty Sources
- Reliability Assessment Framework
- Proposed Model

Cultural Heritage

- Is used to identify structures and/or monuments that were built to document a range of cultural values, achievements of previous civilizations, identity of local communities and the history of Humanity in general.
- Such Heritage is invaluable and should be preserved to reach as many generations as possible.
- Such Heritage comprises unconventional Structural Systems, ex. Monuments, Historic Buildings, etc.

Cultural Heritage



Kanbai El-Djarkassi Mosque

Cultural Heritage

Sultan Barqouq Mosque 1887

Qurqumas Mosque 1880

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Cultural Heritage

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Structural Health Monitoring (SHM)

- SHM emerged as an important tool capable of providing continuous monitoring of special structures.
- High rise buildings and long span bridges are examples of such structures that are today equipped with SHM systems.
- Such systems could also be integral components of smart control systems.
- The following examples are equipped with SHM systems.

Burj Khalifa-Dubai

830 m Height

Sky Tree-Japan

634 m Height

Akashi Kaikyo Bridge-Japan

1991 m Span

Xihoumen Bridge-China

1650 m Span

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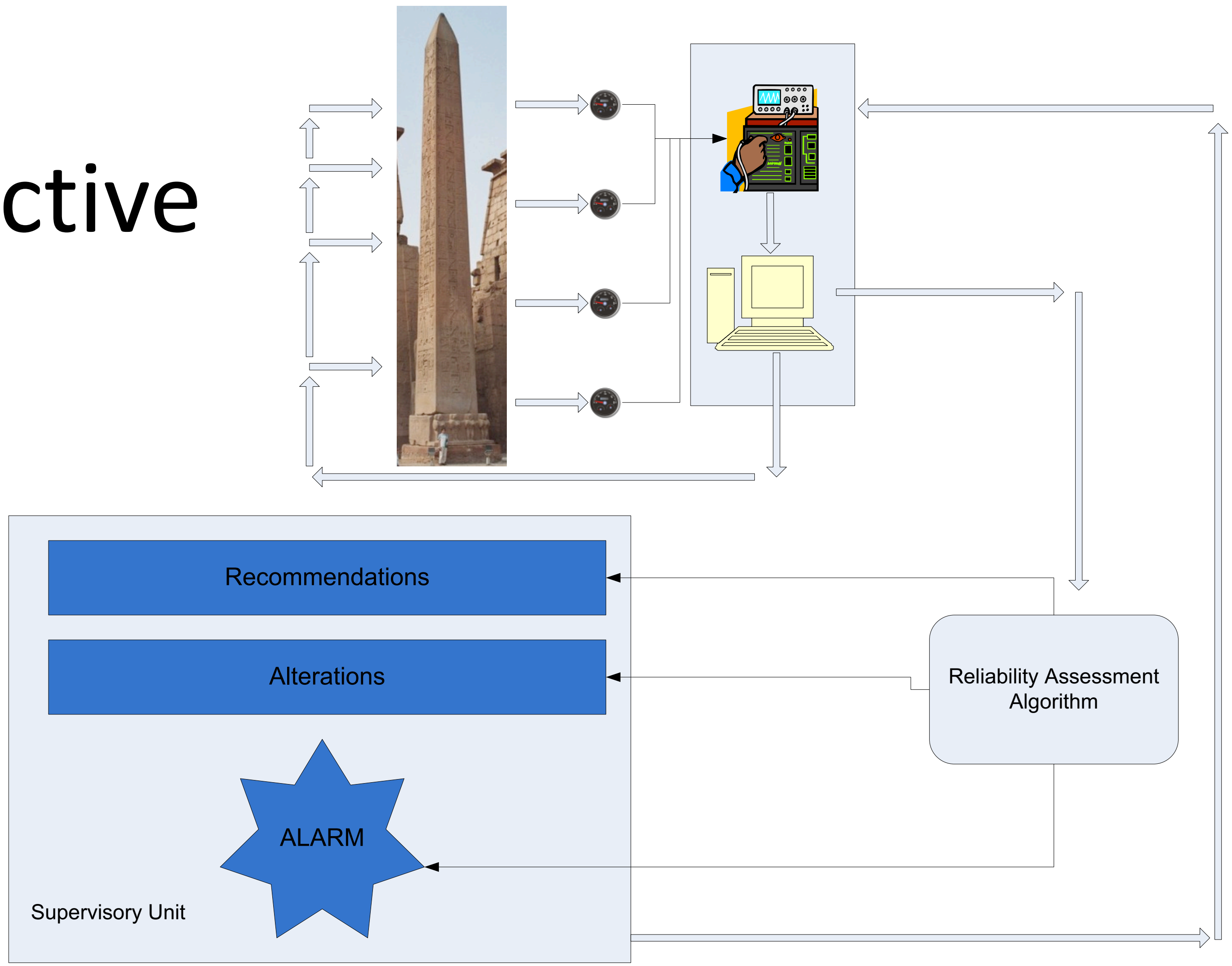
Smart Structural Health Monitoring (SSHM)

- Underpinned by smart technology, such as Fuzzy Logic, Neural Networks, Genetic Algorithms, etc.
- Employs smart sensors with the developments in MEMS.
- To be able to handle vague, uncertain and incomplete information.
- Absence of accurate structural models.

Objective

- Develop a potential SSHM technique to provide:
  - Continuous monitoring.
  - Sound alarms in case an unacceptable deformed shape is identified.
  - Take into consideration various sources of uncertainty.
  - The proposed system shall satisfy an acceptable level of reliability.

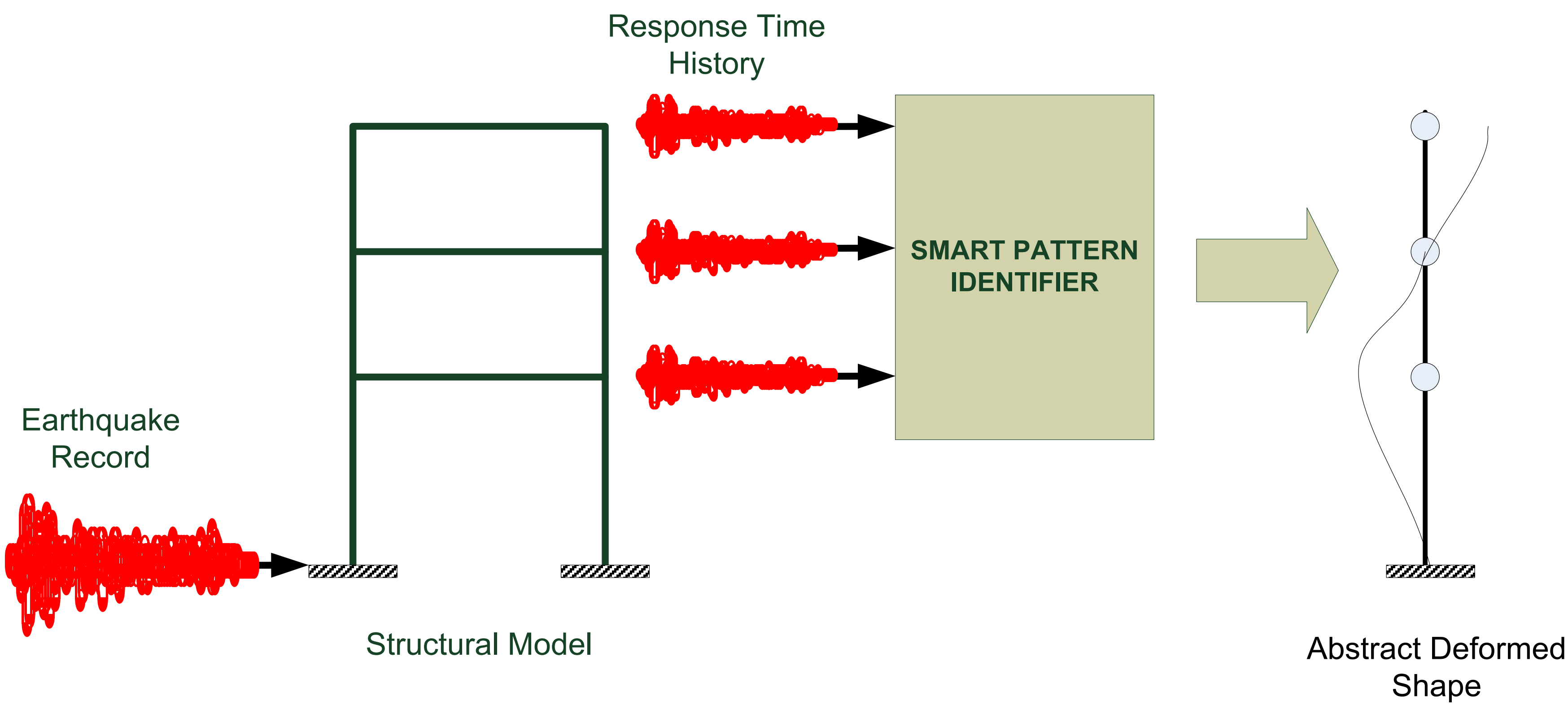
Objective


Recommendations
Alterations
ALARM
Supervisory Unit
Reliability Assessment Algorithm

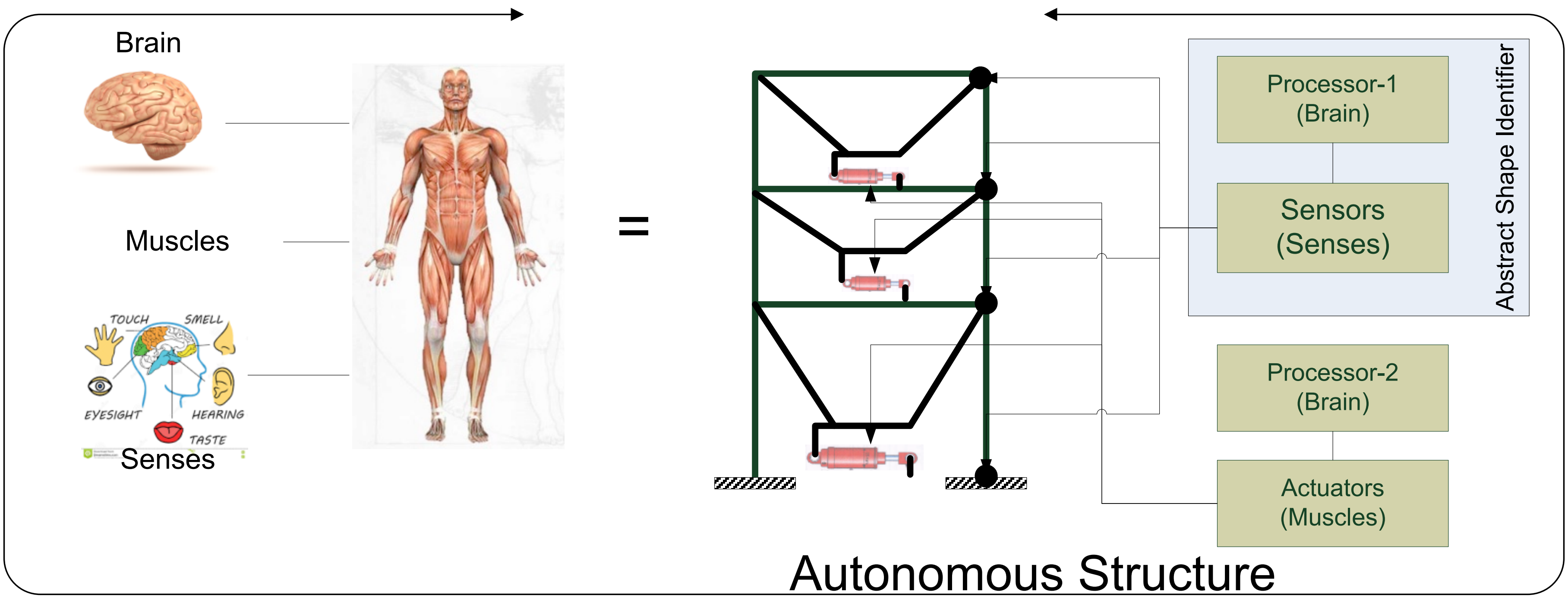
Smart Pattern Identification

- Is a mechanism that was developed as an integral component within a smart controller for structural systems.
- The system should Identify the deformed shape of the monitored monument, in real time.
- If deformed shape exceeds pre-set allowed shapes, sound alarms.
- Propose remedies and/or actions.

Smart Pattern Identification



Smart/Autonomus Structures



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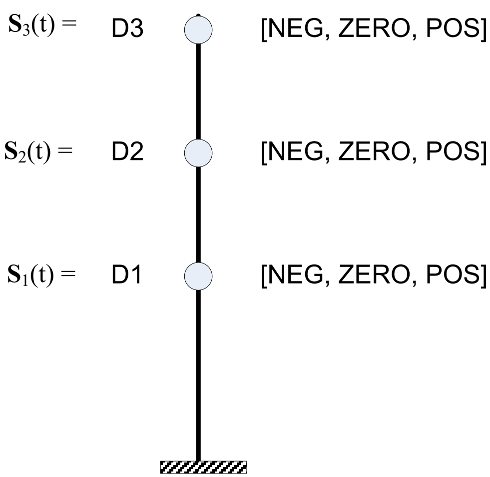
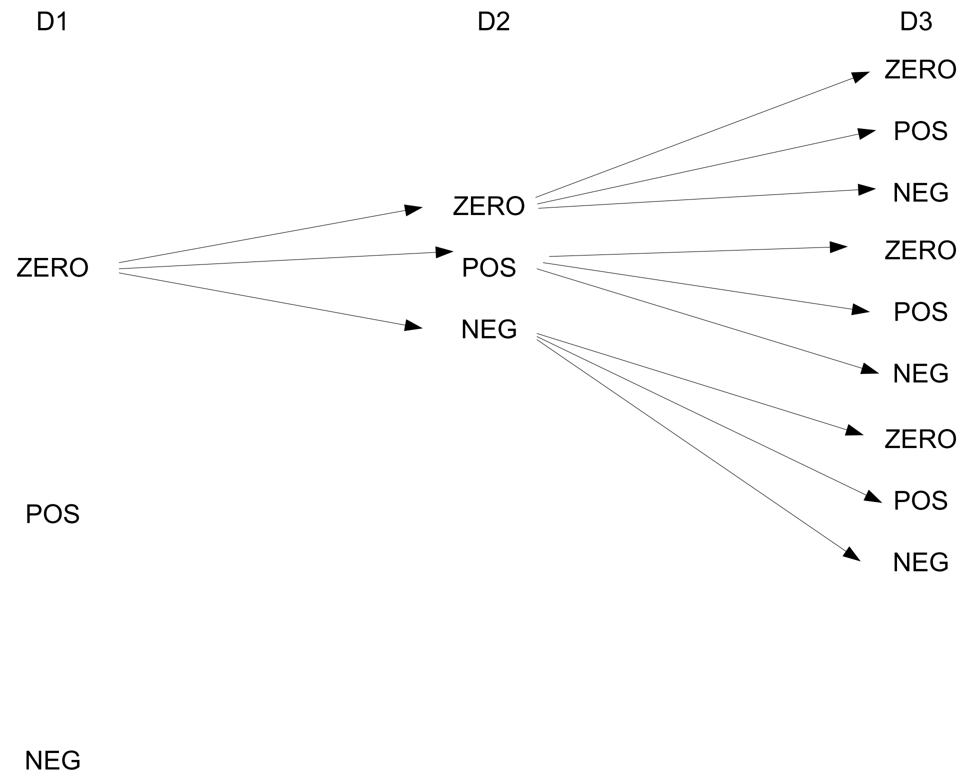
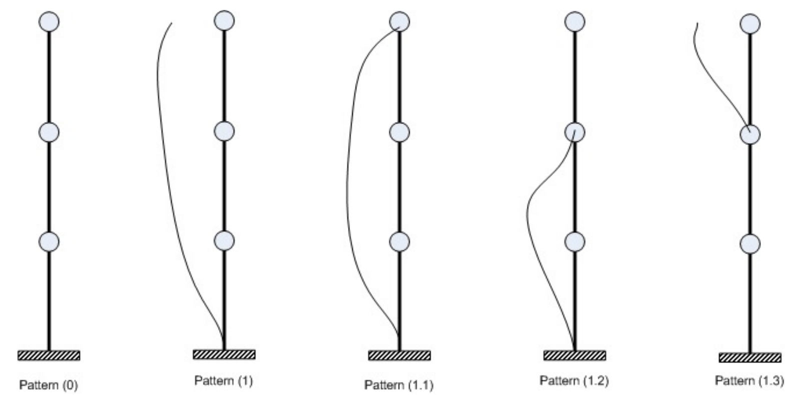
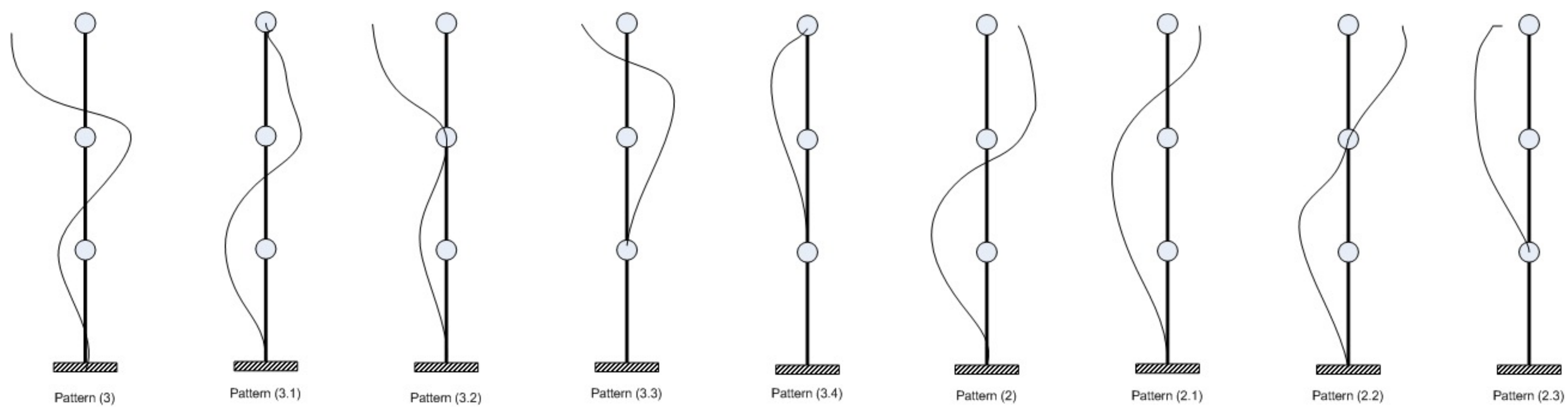

$S_3(t)$ = D3 [NEG, ZERO, POS]
$S_2(t)$ = D2 [NEG, ZERO, POS]
$S_1(t)$ = D1 [NEG, ZERO, POS]


D1
D2
D3
ZERO
POS
NEG
ZERO
POS
NEG
ZERO
POS
NEG
ZERO
POS
NEG
ZERO
POS
NEG

Pattern Classifications

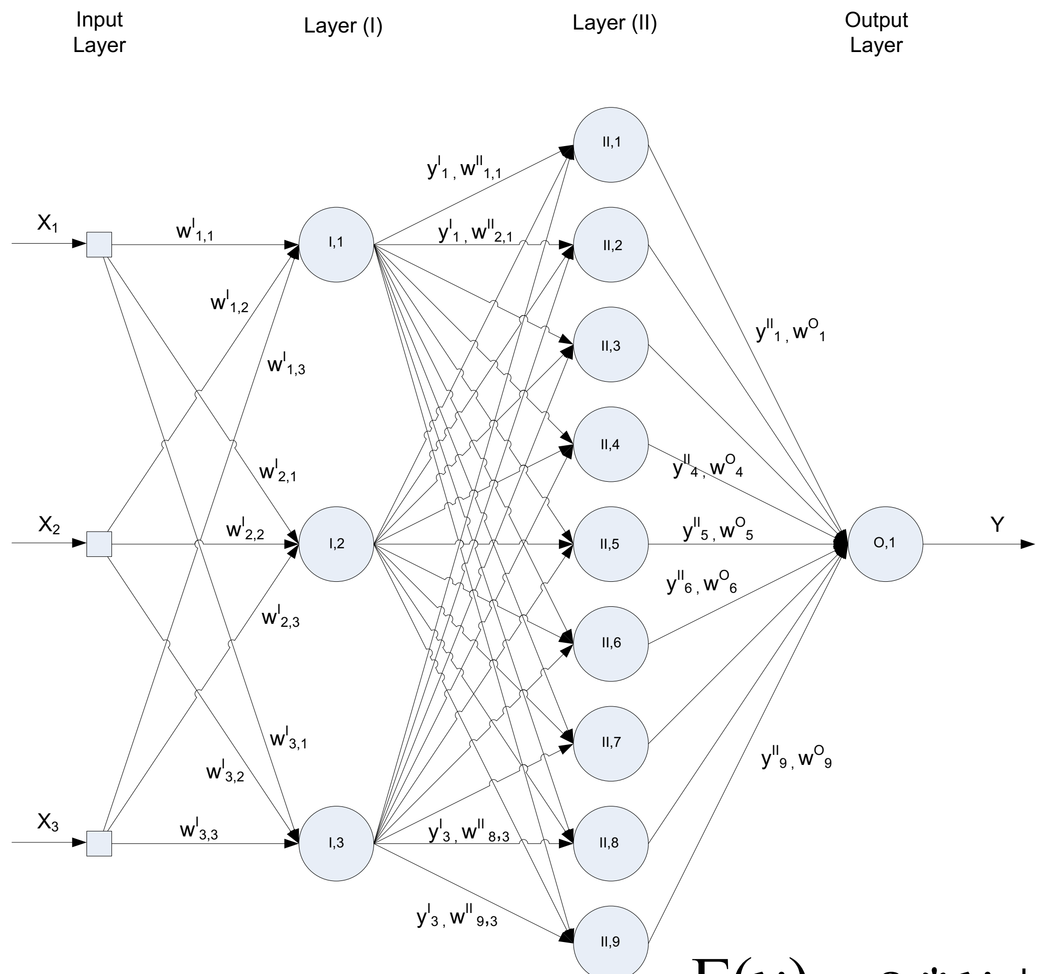
- Smart Pattern Identifiers are trained/designed to identify an abstract deformed pattern of a structural system, real time.





ANN Model

- Input layer
- Two hidden layers
- Output layer
- Activation Functions

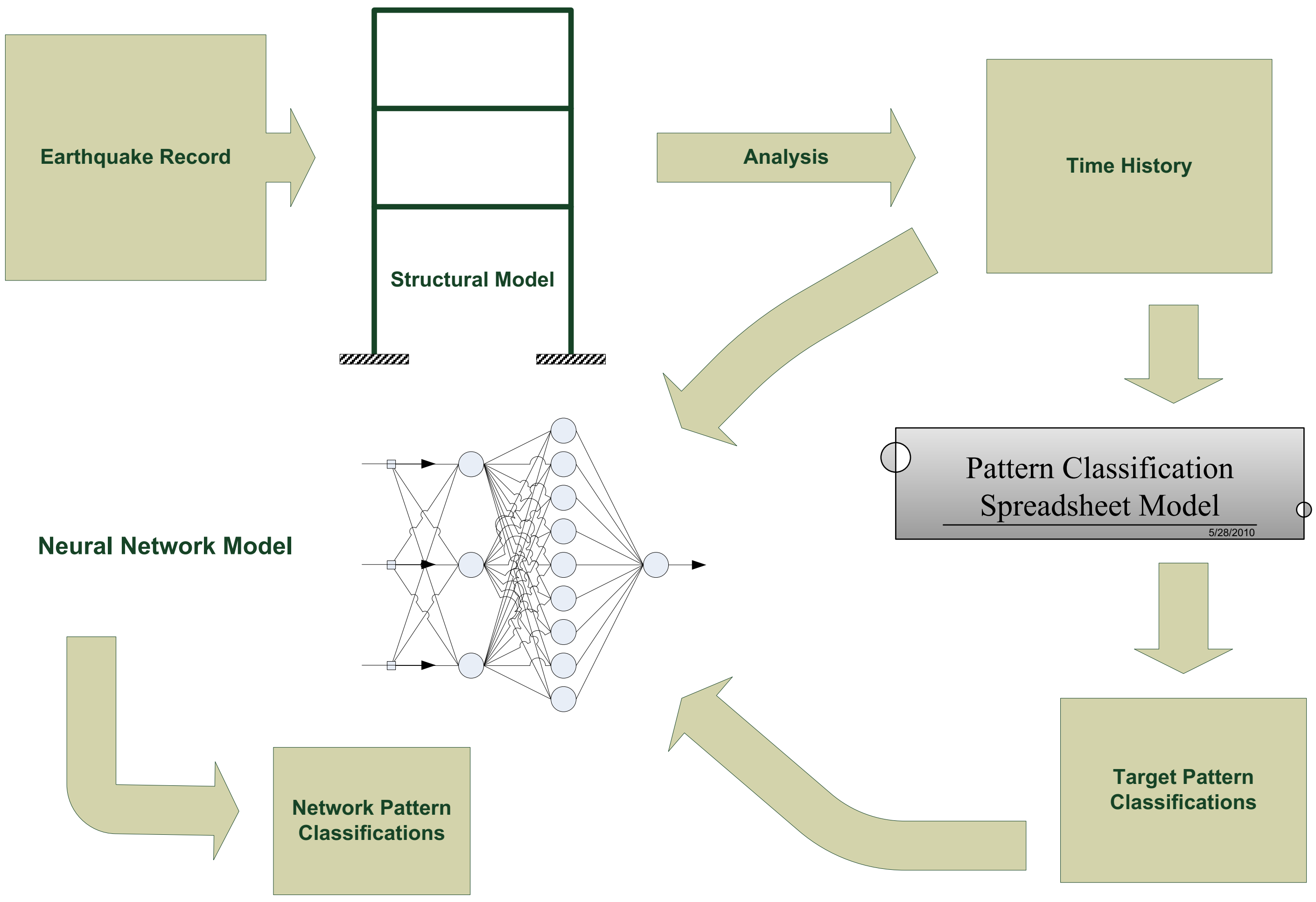


$$\nu^I_i = \sum_{j=1}^{3} w^I_{ij} * X_j$$

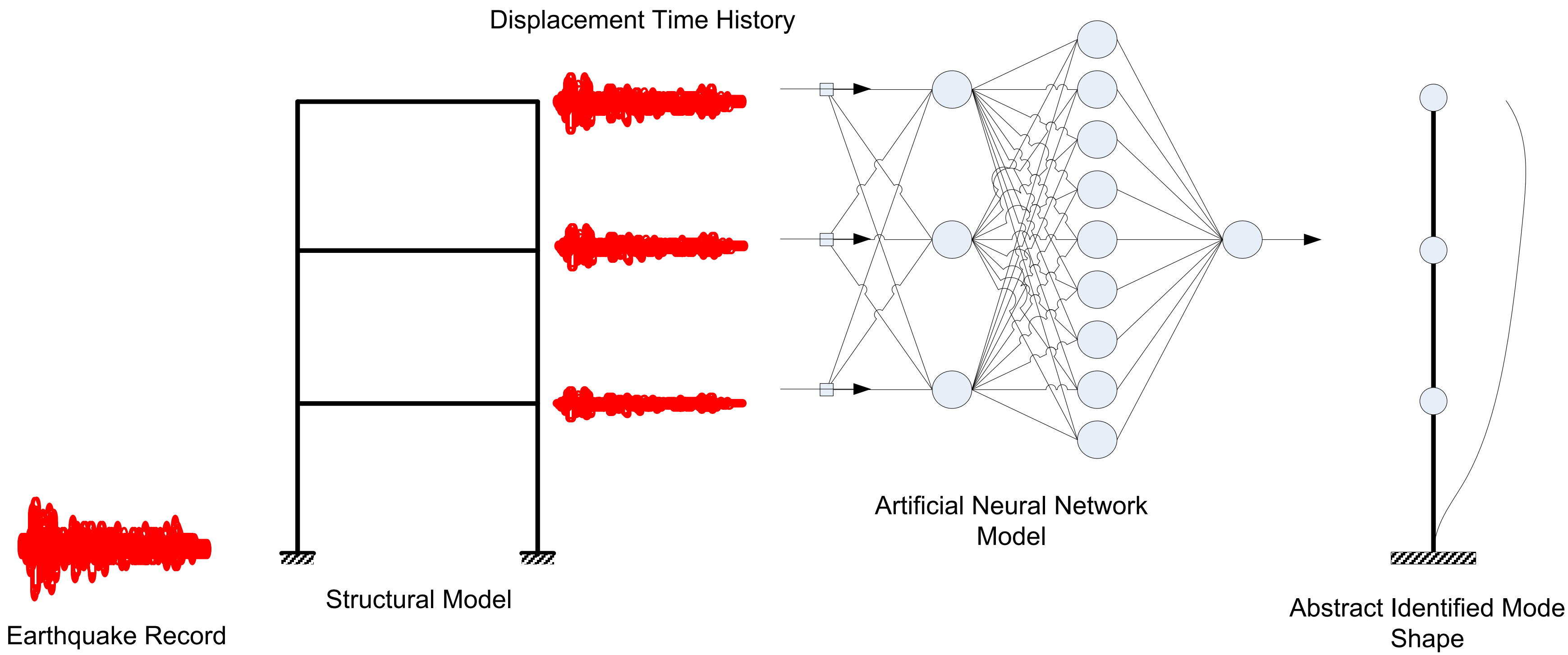
$$y^I_i = \Theta(\nu^I_i)$$

$$\Theta(\nu) = \frac{2}{1+\exp(-2\nu)} - 1$$

$$\Gamma(\nu) = a * \nu + b$$

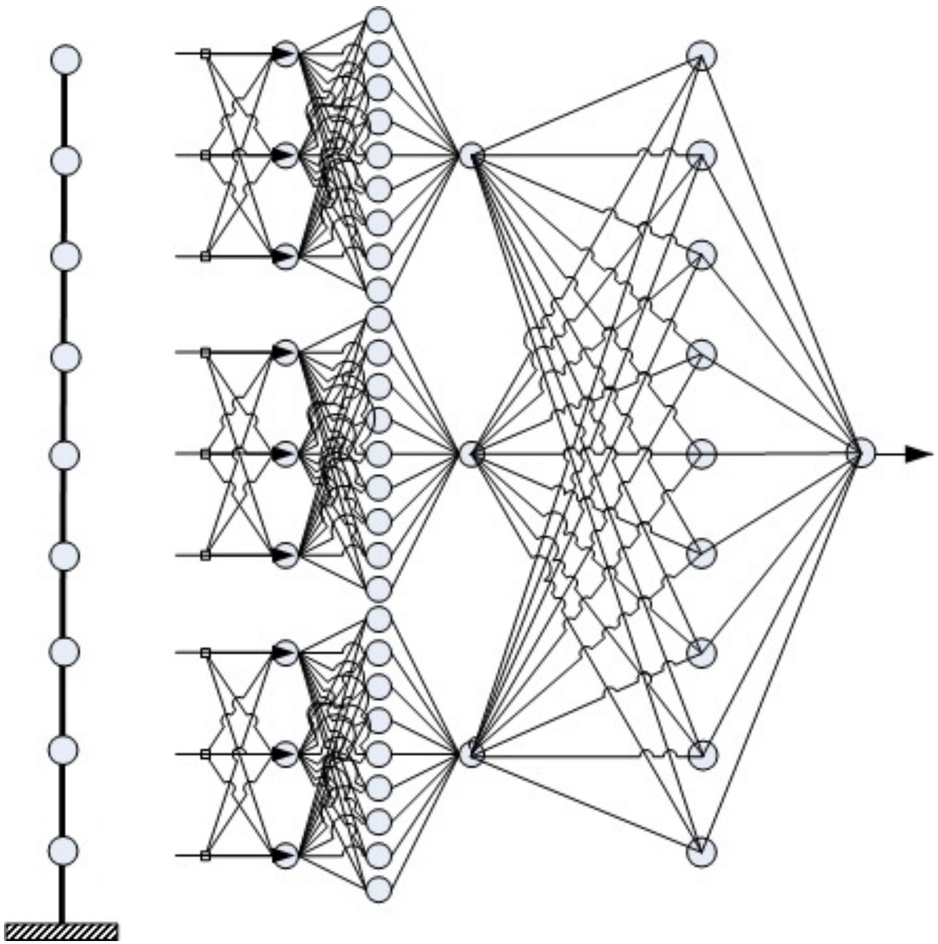


ANN Training Scheme



ANN Performance

Multi Degree of Freedom Systems



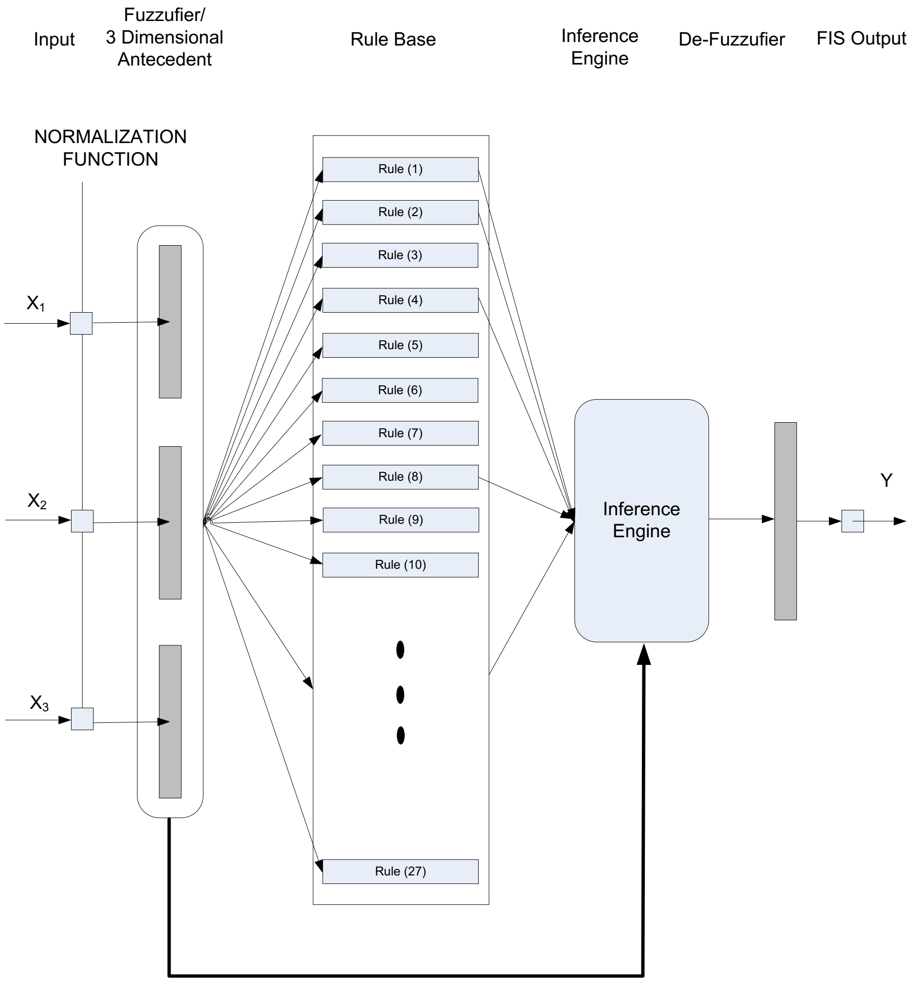
FIS Model

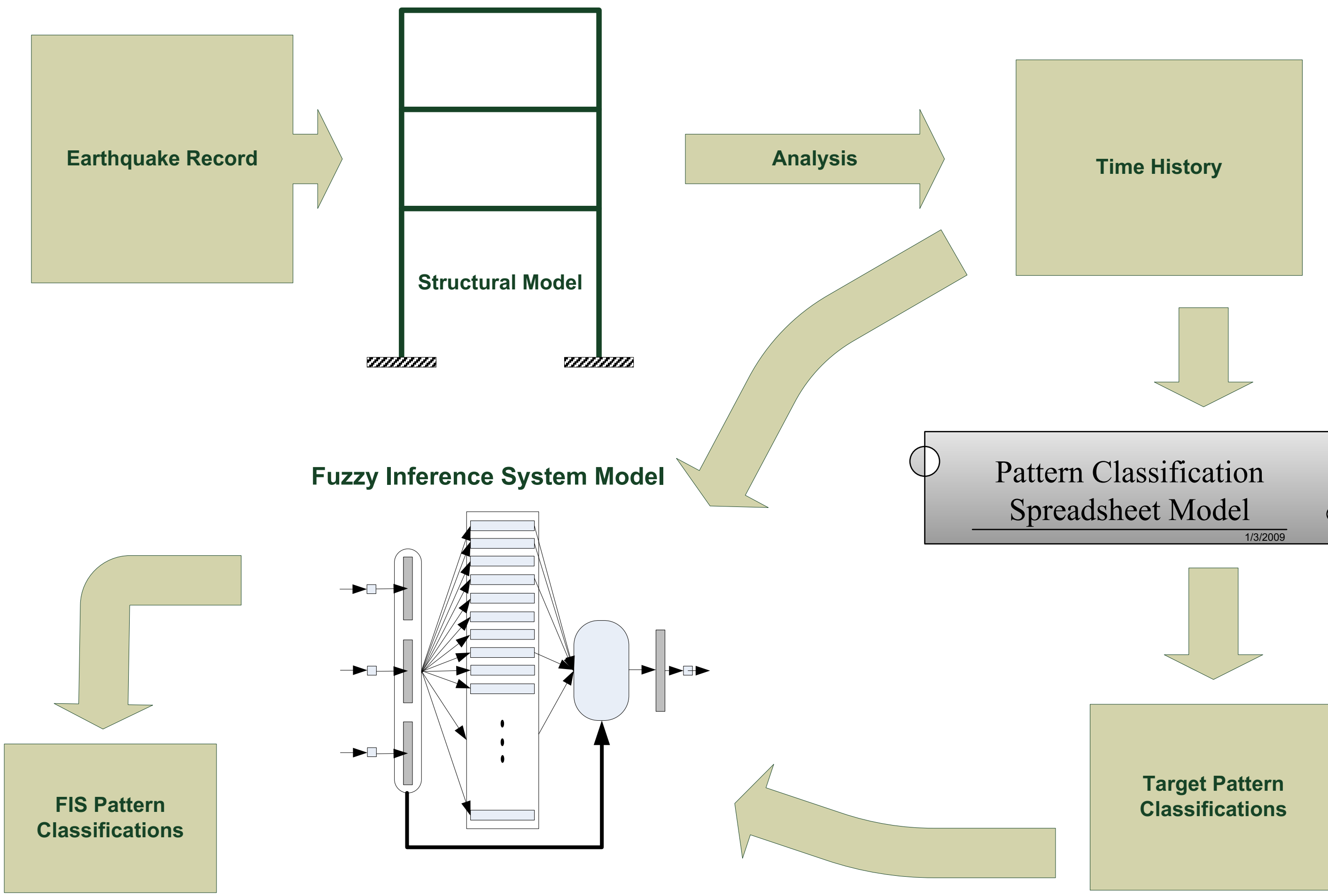
- Normalization
- Rule Base
- Membership Functions
- Inference Engine

$$\mu_{\text{NEGATIVE-LEVEL}_i}(x) = \begin{cases} \dfrac{x}{LB} & \text{for } LB \le x \le 0 \\ 0 & \text{for all other values of } x \end{cases}$$

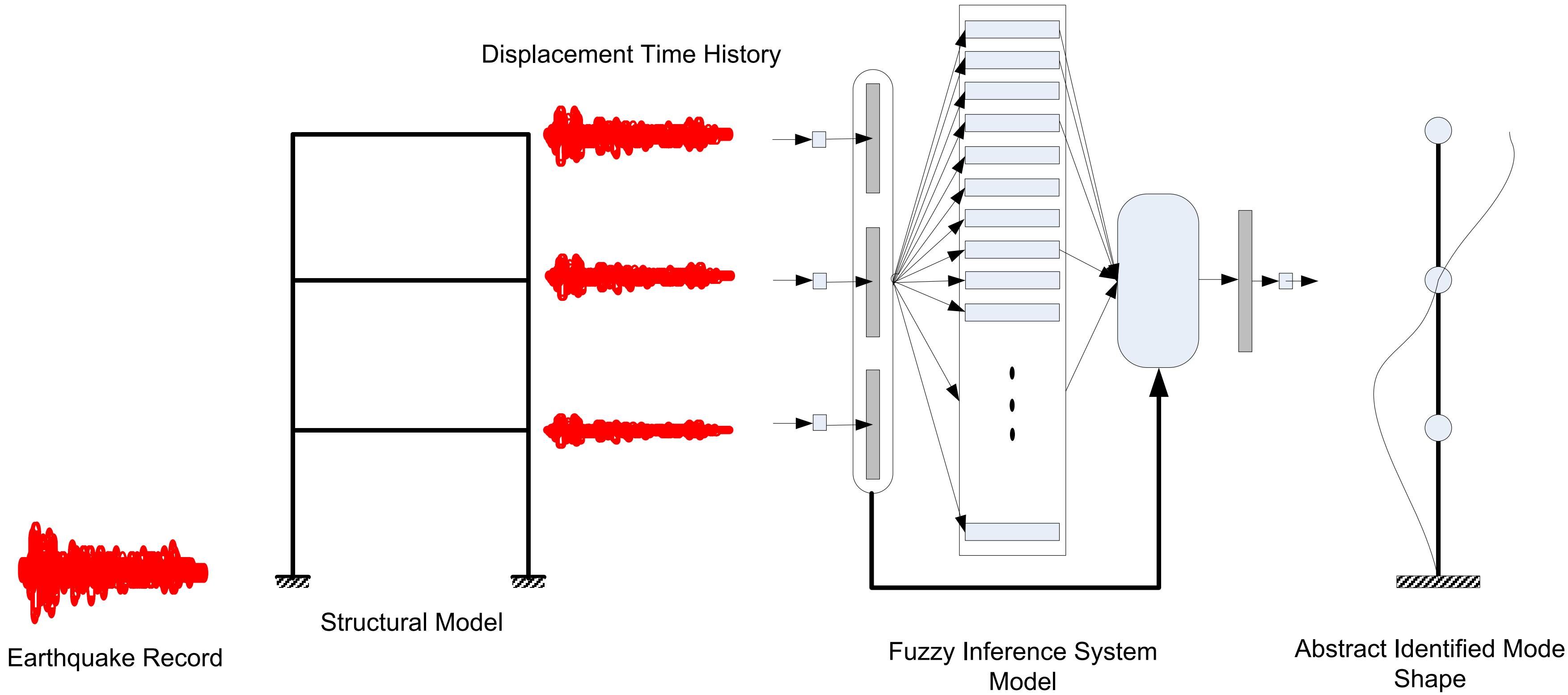
$$\mu_{\text{ZERO-LEVEL}_i}(x) = \begin{cases} -\dfrac{1}{10^{-6}}\left(-10^{-6} - x\right) & \text{for } -10^{-6} \le x < 0 \\ \dfrac{1}{10^{-6}}\left(10^{-6} - x\right) & \text{for } 0 \le x < 10^{-6} \\ 0 & \text{for all other values of } x \end{cases}$$

$$\mu_{\text{POSITIVE-LEVEL}_i}(x) = \begin{cases} \dfrac{x}{UB} & \text{for } 0 \le x \le UB \\ 0 & \text{for all other values of } x \end{cases}$$





FIS Testing Scheme



FIS Performance

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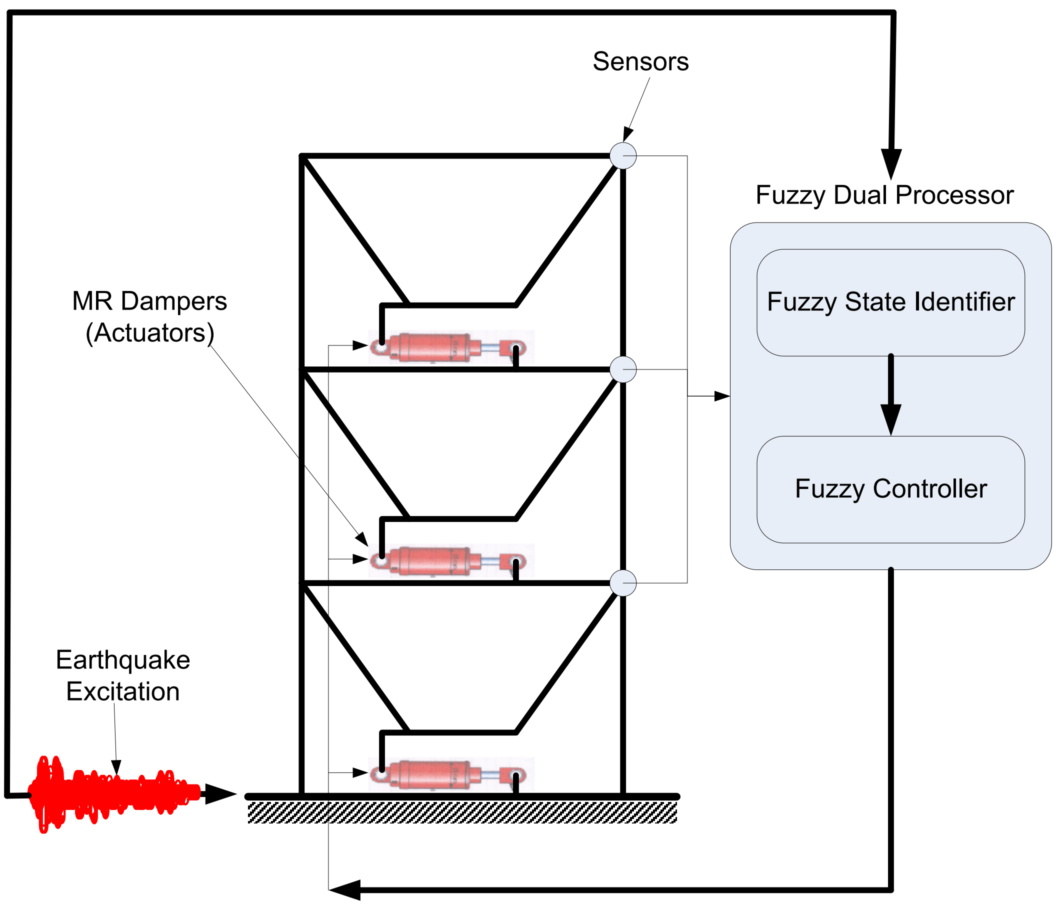
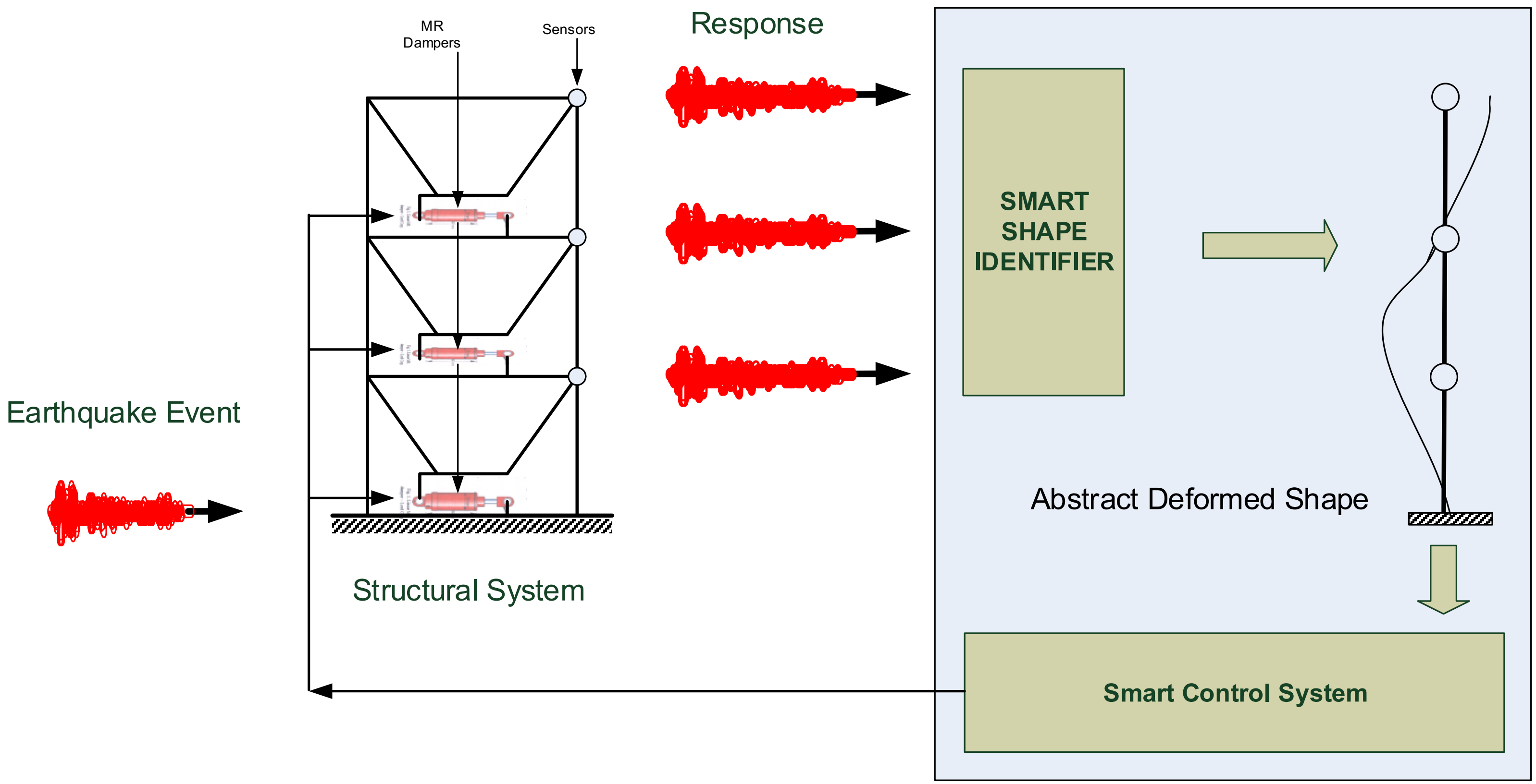
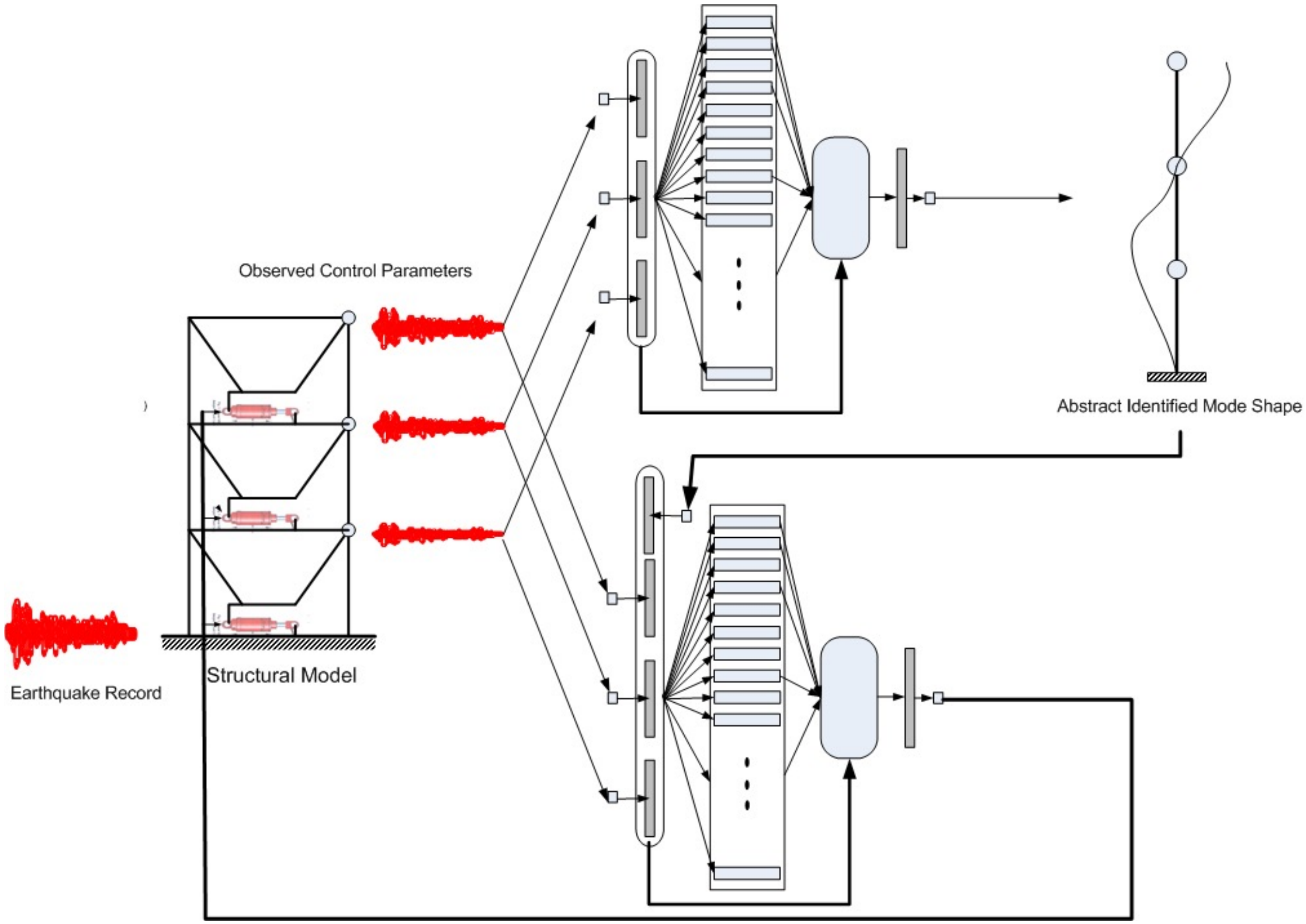
Potential Smart Control Scheme



Potential Smart Control Scheme



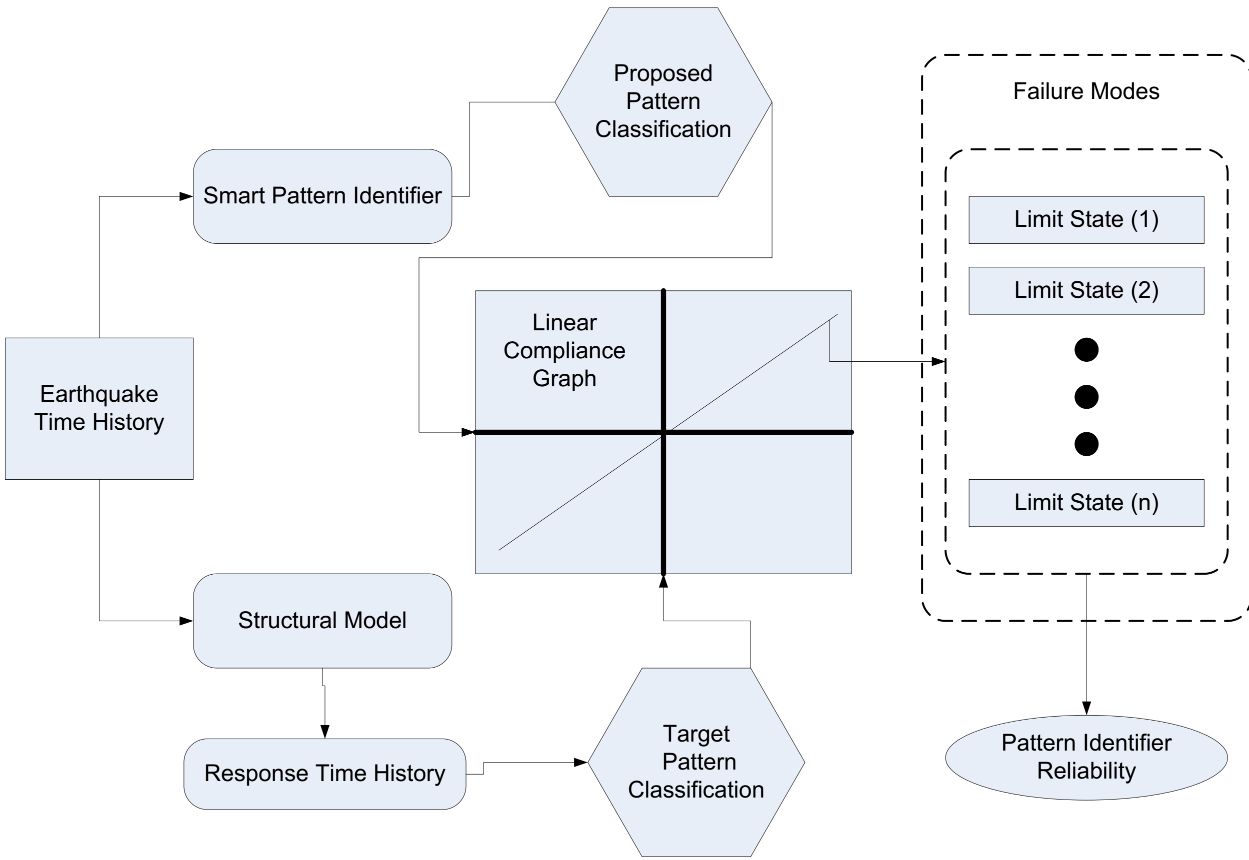
Potential Smart Control Scheme



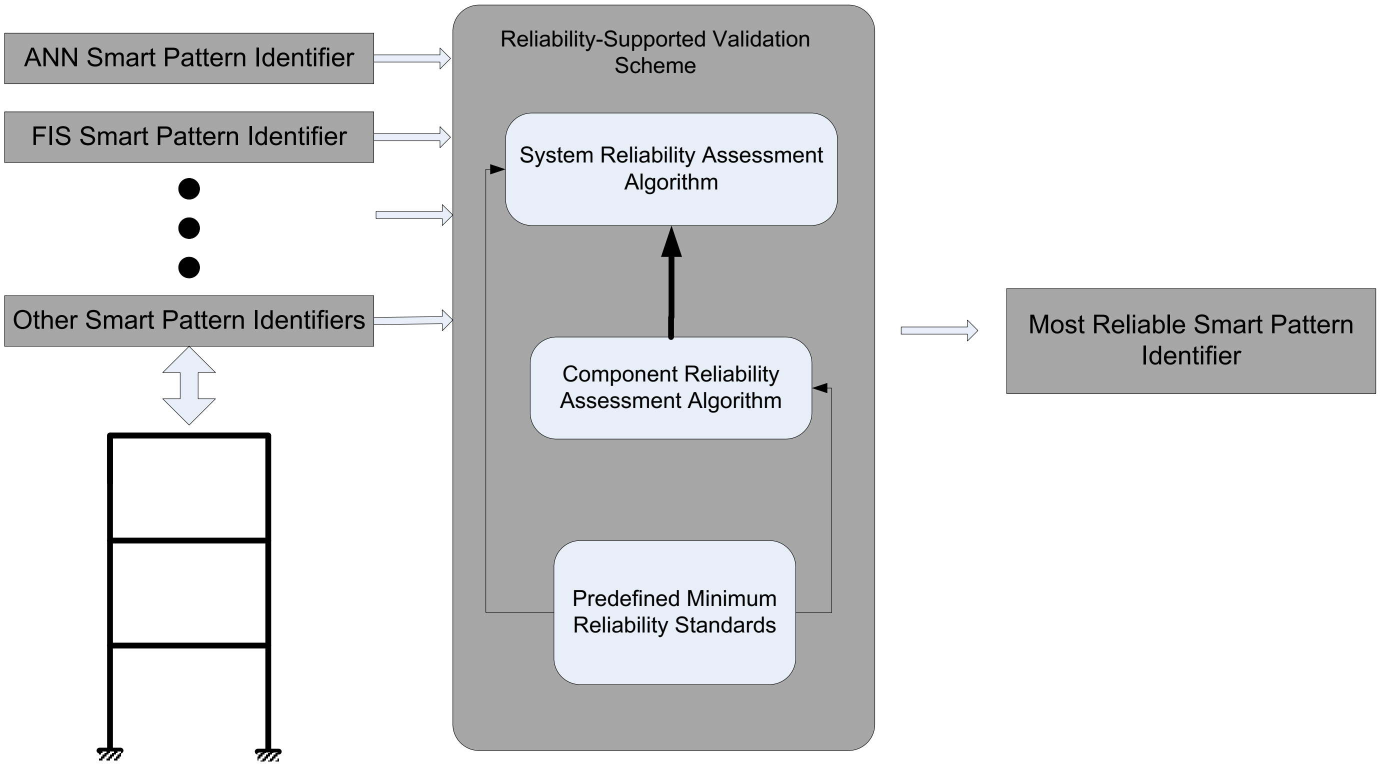
Reliability & Uncertainty Sources

- Training Process
- Forcing Earthquake
- Rule Base
- Membership Functions
- Other…

Reliability Assessment Framework

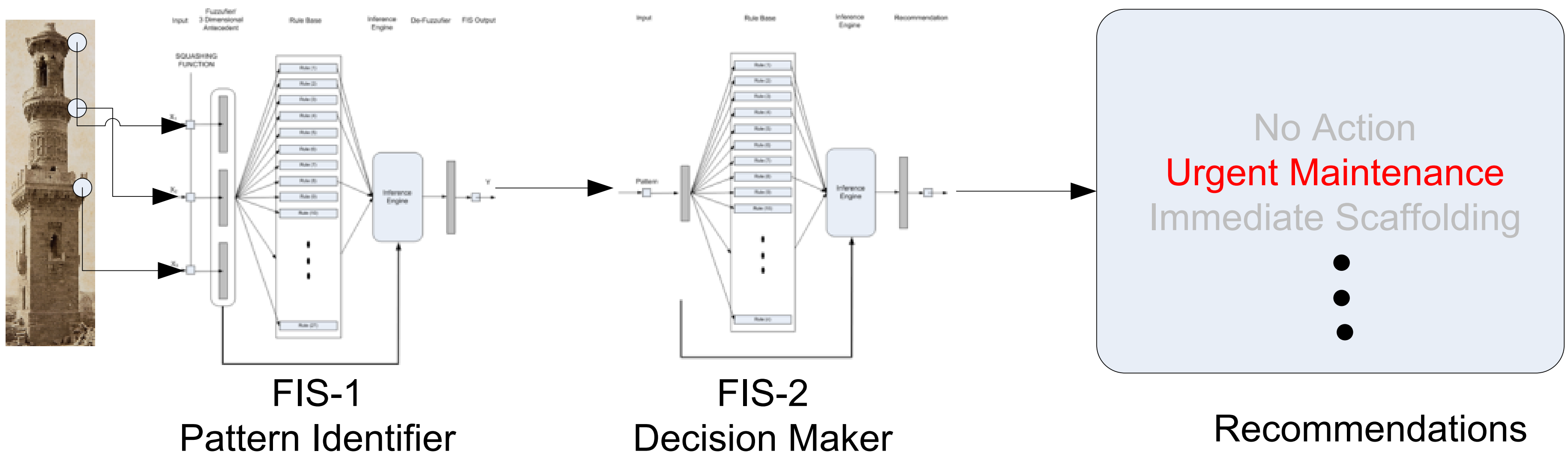


Reliability Assessment Framework



Cultural Heritage Preservation Workshop-July 13th 2021

Proposed Model



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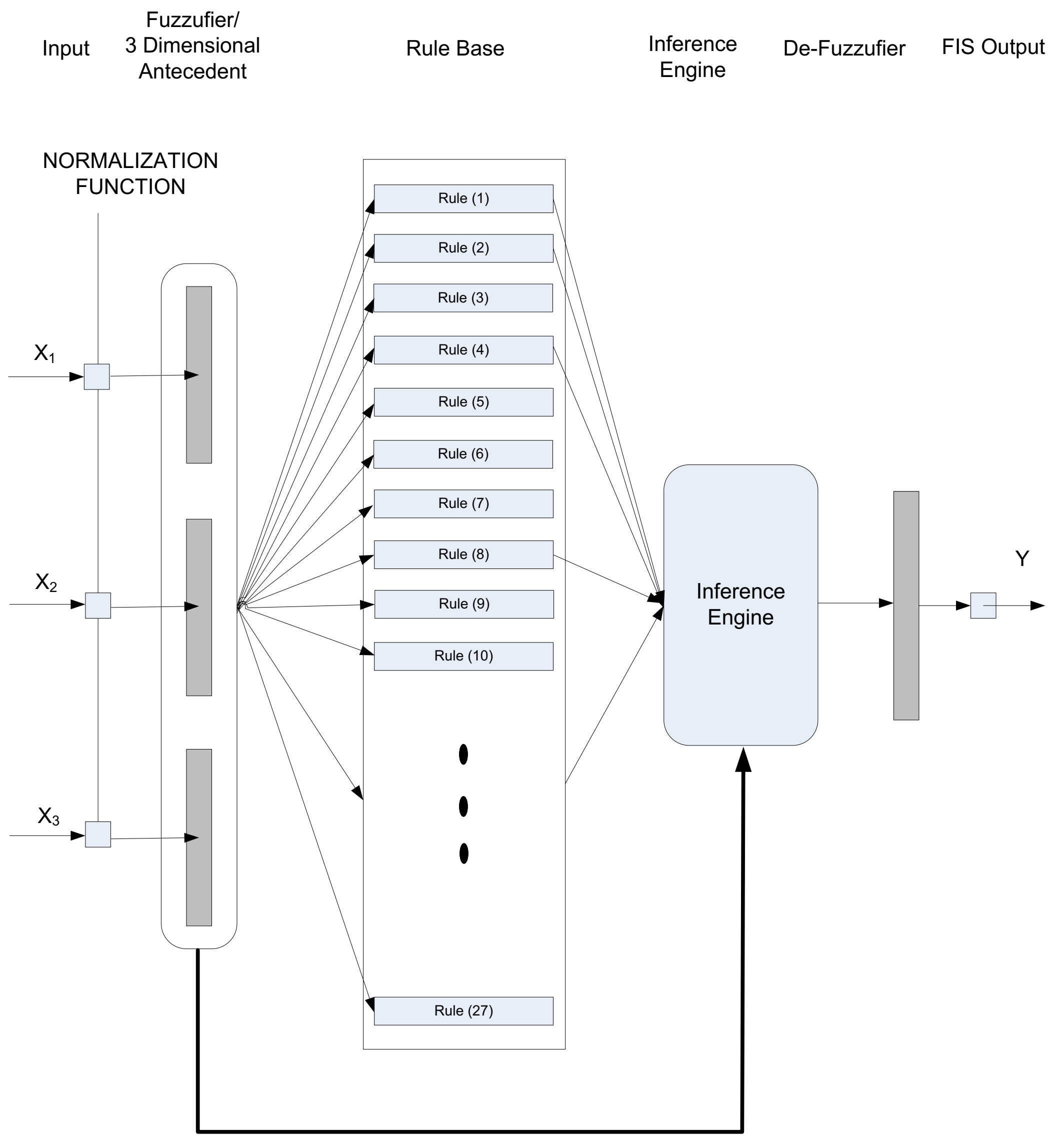

FIS Pattern Identifier

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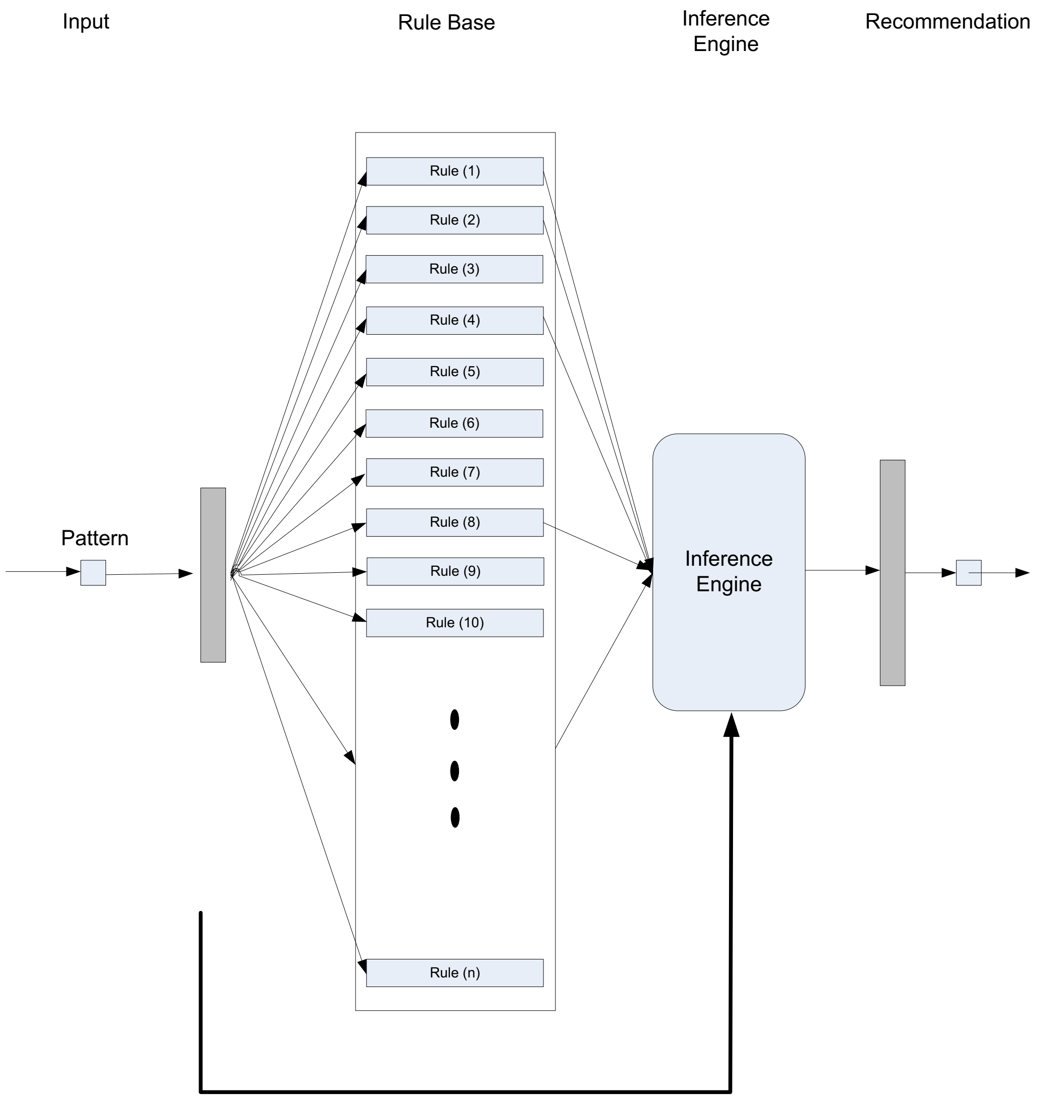
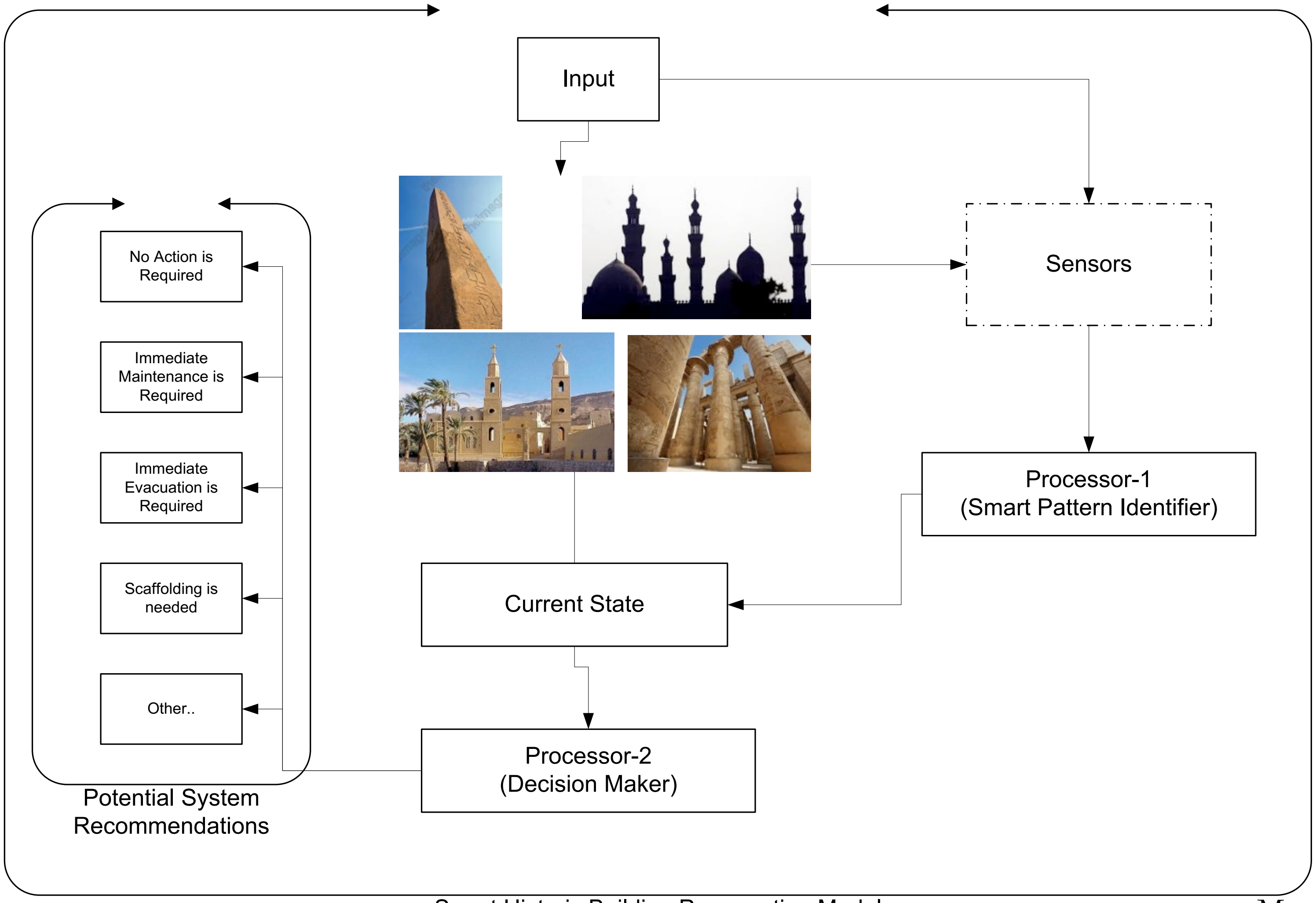


FIS Decision Maker

Proposed Model



Smart Historic Building Preservation Model

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THANK YOU!!