# *My spring break in Kunming*

## Classification of Early Warning Systems

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# Motivation to classify EWS

- Question - "given the  minimal response time and geographical coverage, what are the hazards, with a known Time-to-Impact, the LM-HWS is effective?"
- Answer - "Enumerate the designed, capabilities and capacity of the LM-HWS."
- Question - "How can the LM-HWS be extended to serve other EW objectives?"
- Answer - "Apply a design framework to decompose the LM-HWS to determine the elements that need be enhanced"
- Example - "Can the LM-HWS be used as a Dam Failure EWS?"
- Answer - "No, not for warning the communities in the shadow of the dam, but perhaps to warn the communities downstream in the shadow of dams part of the cascading system of dam"

# What is classification

- Answers the question “What are the objects of a given type that stand up to some equivalence?”
- Gives a non-redundant enumeration method to place each object in a single class
- Ability to unambiguously exemplify the key properties and behavioural nature of the objects that share those common properties

Vitamins

Proteins

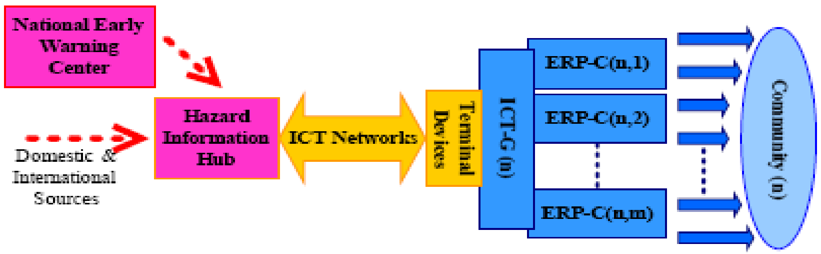
Carbohydrates

# Importance to planners and policy makers

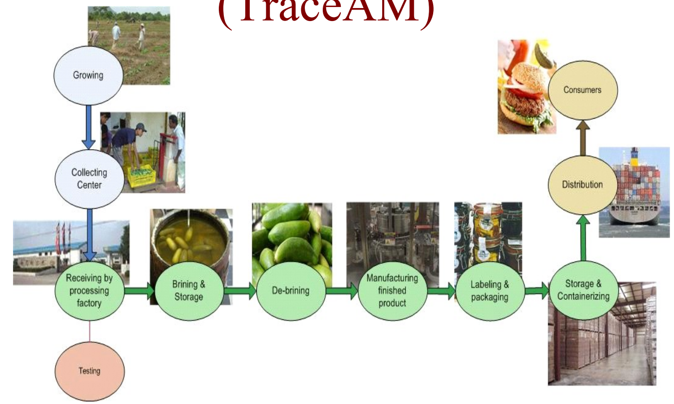
- Help planners and designers deeply **understand the characteristics and potential** (capability and capacity) of a given EWS
- Determine the possibility of extending a given EWS to serve an alternate objective
- Create an interest in forming a field of study by **analogy with other fields** of study
- Initiate a way forward in the **systematic design, evaluation, and development**
- Setting up a framework to **delineate the intellectual boundaries** of EWS, current focus only in engineering, economics, and business
- Eliminate the **ambiguity in terminology** and strategies used in designing EWS
- Have a mathematical framework for **future academics and practitioners to use** as a basis to carry out out there future research
- **Change the paradigm** of an optimal design to be based on the forecasting model to the decision maker's preference

# Four examples used to illustrate the theory

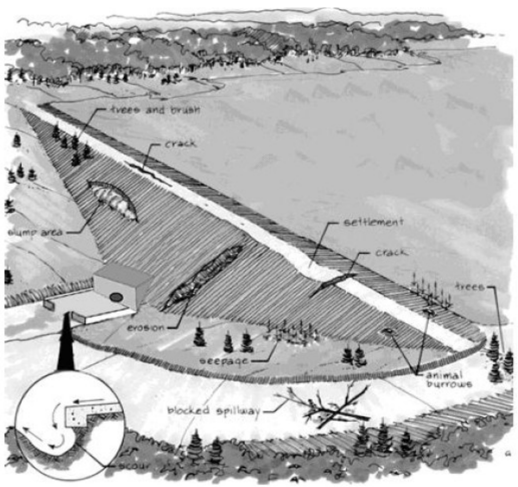
## Community-based Last-Mile Hazard Warning System (LM-HWS)



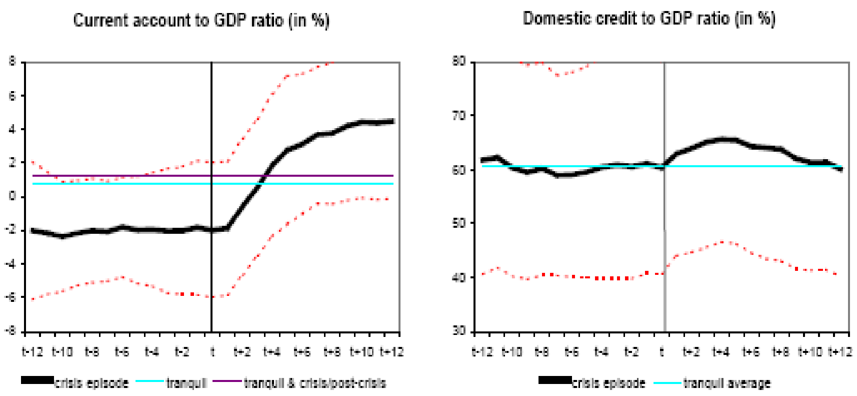

## Traceability of Agriculture Markets (TraceAM)




## Dam Failure EWS (Dam-FEWS)



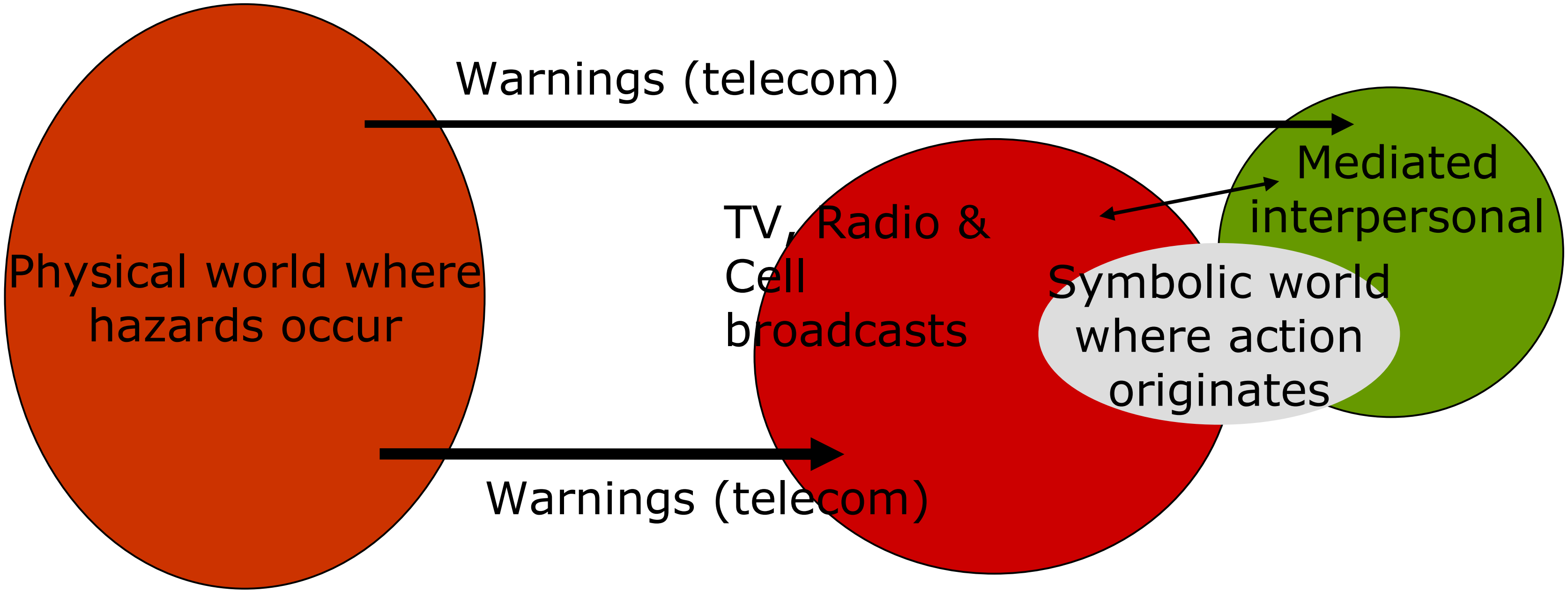

## Financial EWS



# Prior ambiguous schemes

- Hazard classification (implicitly apply to natural hazards but explicitly not to all hazards):
  - Sudden-onset 0 – 30 minutes
  - Rapid-onset 1-3hours
  - Slow-onset 8 – 10 hours or more
- Multiplicity of events: single-hazard, multi-hazard, all-hazard
- Decision model
- Domain: financial, flood, tsunami, cyclone, etc

# Samarajiva Conjecture




The physical, the symbolic & their linking through ICTs, simplified **More time to run; more lives saved**

- ICTs enable the linking of physical world within which hazards occur and symbolic world of the human likely to be harmed by those hazards, so that they may take life saving action. But the effective linking of these worlds requires not only ICTs, but also the existence of institutions that allow for the effective mobilization of their potential (*Samarjiva: mobilizing ICTs for disaster warning, 2005*)

# Definition “EWS”

- **Definition** “Early Warning System” (EWS): A chain of communication systems comprising sensor, detection, decision, and broker working together forecast and signal any disturbance that will adversely affect the instability of the physical world, giving sufficient time for the response system to effectively rationalize and prepare the response actions to minimize the impact on the stability of the physical world.

- the 'E' in EWS is for the work “effective”, more so than 'early'

- identifies disturbances in the system likely to have a significant impact

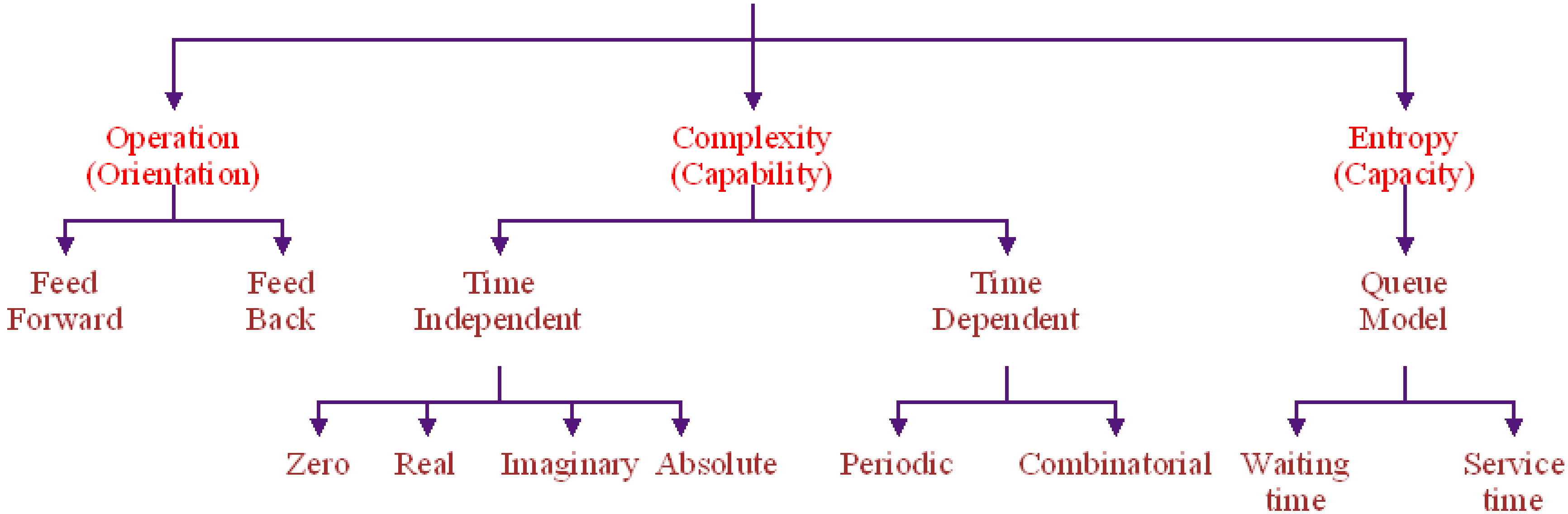
- disseminates information relevant to the needs of the controller (response system)

- timely, so as to enable appropriate decision making (such as resource allocation)

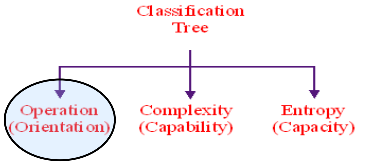
- facilitate appropriate adoption, and identify further response requirements

- key ingredient is the ability to respond appropriately

# Overview of Classification Tree




- Operational orientation
  - Operations: sensing, detecting, deciding, brokering, responding (analogy: +, -, x, / in algebra)
  - Orientation: forward path or feedback (Inside or outside of the crisis window)
  - Before of after the tipping point
- Complexity of the system
  - Time independent complexity: zero, real, imaginary, & absolute
  - Time dependent: combinatorial & periodic
  - Synonymous with the physical part of the space or the domain the EWS exists in
  - Indicates the capability
- Entropy of expected state
  - Expected waiting time
  - Expected service time
  - Indicates the actual capacity

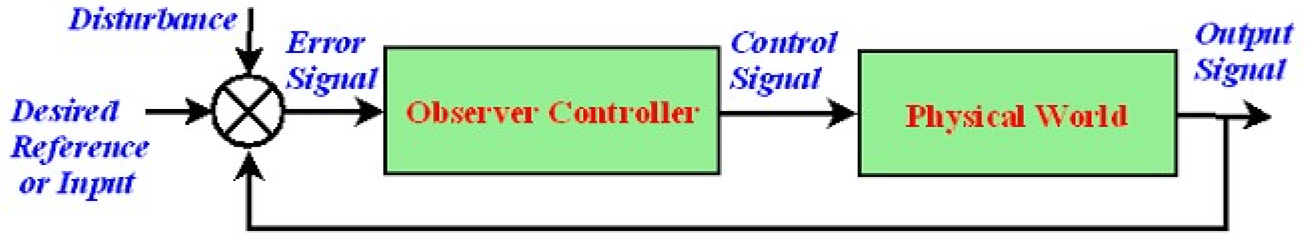



# Predictor Corrector Model

**Forward Path Observer Controller**

example: Cyclone or Tsunami EWS

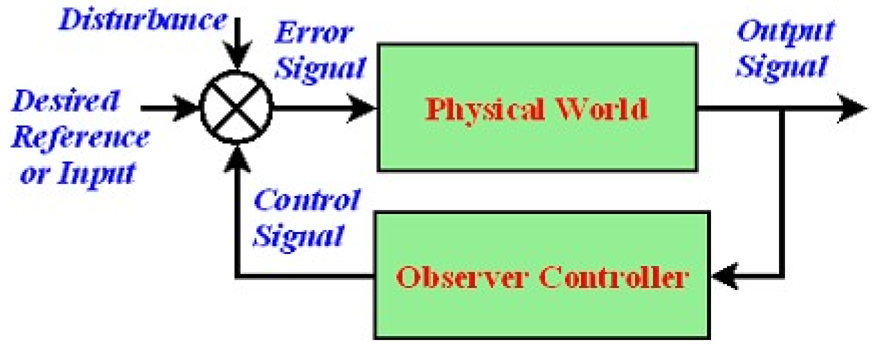
(Outside the crisis window)




**Feedback Path Observer Controller**

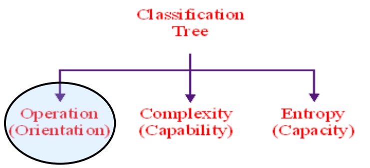
example: Biosurveillance or Traceability

(Inside the crisis window)

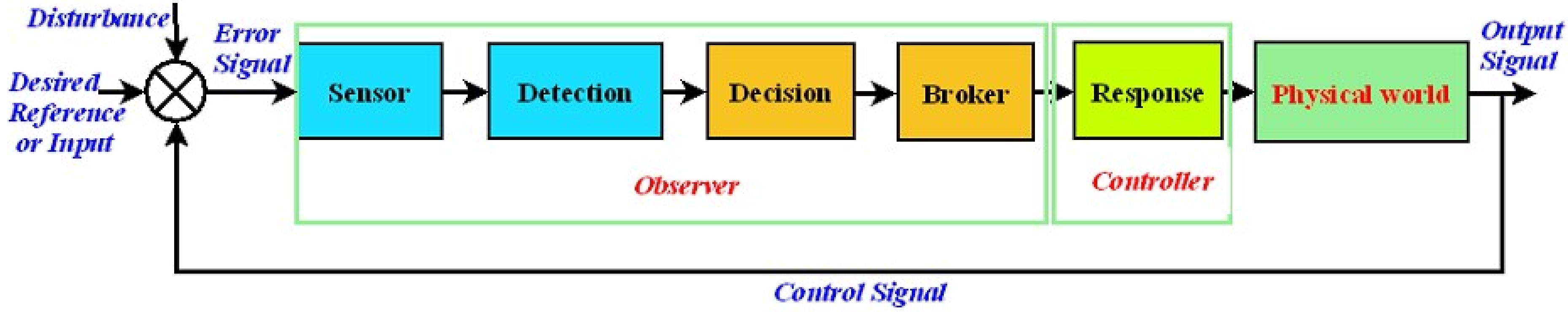



**Proposition**: "EWS are a class of Observer-Controller Systems": An EWS is a observer controller system comprising a chain of sensor, detection, decision, broker, and response systems; where the observer is made of the first four – sensor, detection, decision, & broker systems and the controller is made of response systems.

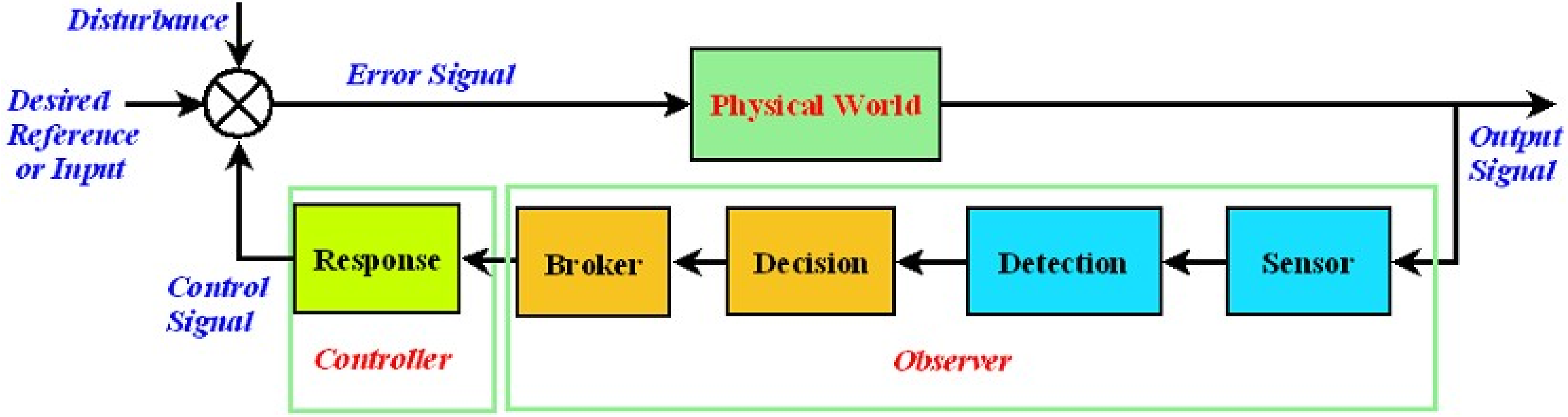
# Components of EWS



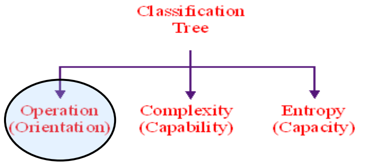

## Forward Path Observer Controller



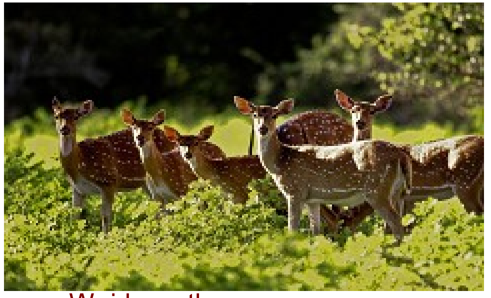

## Feedback Path Observer Controller



# Leopard EWS in the animal kingdom







All photographs by Dr. Sawan Waidyanatha

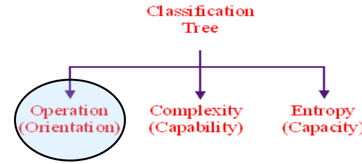
Sensor: Grey Langa scan the surrounding for threats

Detection: they see a Leopard  approaching and begin screaming

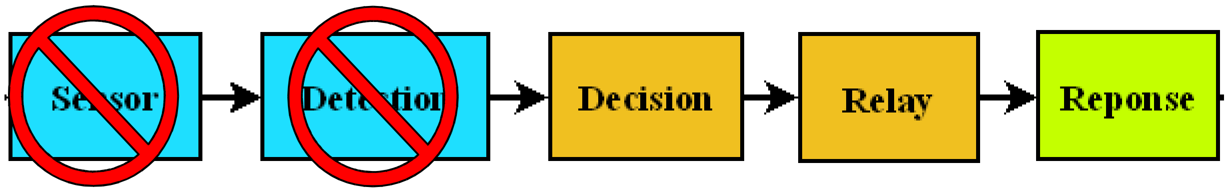
Decision: the Chital Buck (decision maker) assesses the situation and alerts the pack

Relay: adult (mother) Chitals relay the threat to the rest of pack mostly the fauns

Response: 1) if time permits evacuate the areas or 2) form a semi circle tucking fauns between adults and bark at Leopard




# Leopard EWS in the animal kingdom

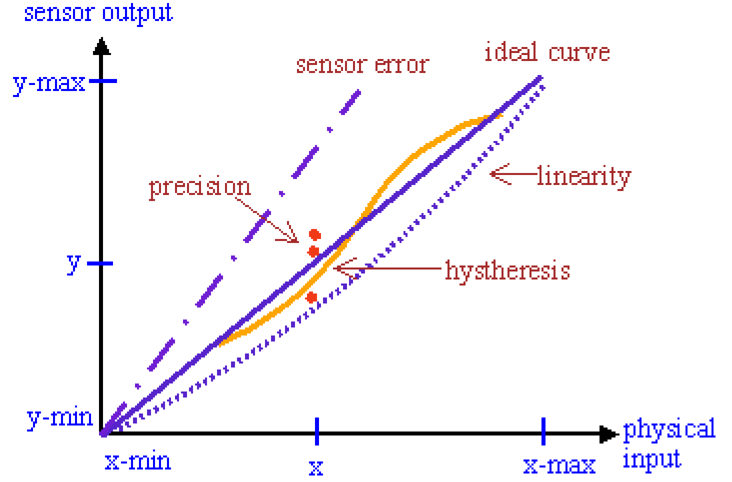



- In the open field there are no Gray Langa to sense and detect approaching threats
- out in the open system is weak
- all elements of the communication chain must coexist if system is to be effective

**Proposition**: "*EWS necessary and sufficient components*" Chain of Sensors, Detection, Decision, Broker, and Response are a necessary and sufficient components of an effective EWS.

Sensor

# Characteristics of a sensor



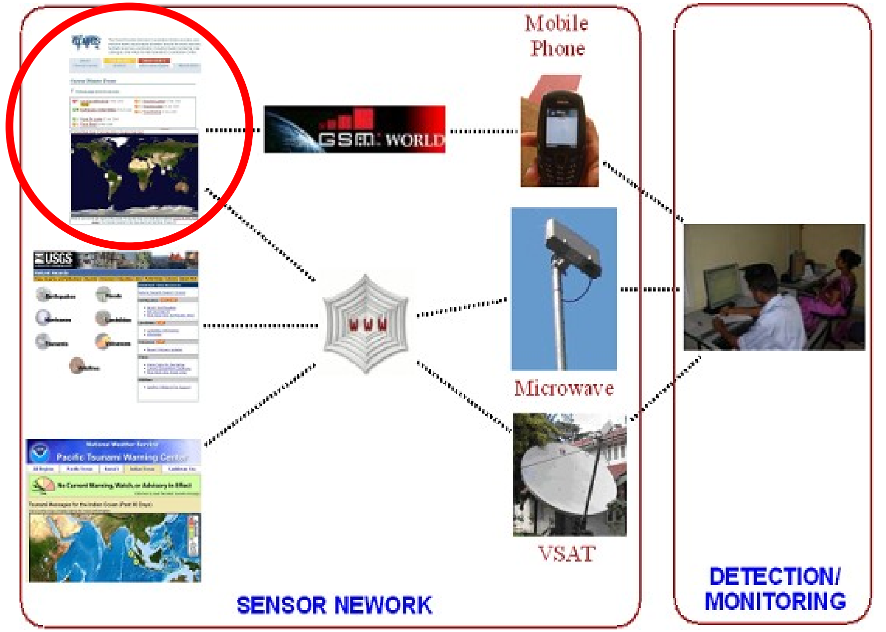

- A few sensor types
  - Location, motion, orientation sensors
  - Environment monitoring sensors
  - Thermal, pressure, and optical sensors
  - Information sensors
  - Biological sensors
- Trusting a sensor
  - Quality aspects
    - Sensitivity – slope of the characteristic curve
    - Sensor error – departure from the ideal slope
    - Sensor range – minimum and maximum values than can be measured
  - Performance criteria
    - Accuracy- difference between the actual value and the indicated value
    - Resolution – smallest detectable incremental change that can be measured
    - Precision – degree of reproducibility of same result
    - Linearity – extent of which actual measure curve departs from the ideal curve
    - Hysteresis – regardless the direction the change is made sensor should follow

Sensor

# Example: LM-HWS Information sensor system

SOURCE = GDACS

- ***Sensitivity*** – quantity of information received near constant w.r.t structure:
  - Summary
  - Earthquake Event (parameters: source, magnitude, depth, location, country, province, region, time)
  - Earthquake Impact Details (parameters: potential effected people, resilience/vulnerability, secondary effects)
  - Disclaimer
- ***Sensitivity error*** – information structure is constant
- ***Sensor range*** – earthquake
  - 5.6 < magnitude
  - 0 < depth <100km
  - Location = distribution of seismic sensors
- ***Accuracy*** – cannot determine unless terminal device or software is faulty or in displaying info
- ***Resolution*** – minimum variance in parameters
  - Magnitude = 0.1
  - Depth = 1
  - Location (Lon/Lat) = (0.001, 0.001)
  - Population = 1




- ***Precision*** – the change in information for the same magnitude, depth and location of a tremor
- ***Linearity*** – information such as resilience/vulnerability may vary with respect to the availability of information; thus information curve deviating from ideal curve
- ***Hysteresis*** – does not exist in this example

Sensor

# Dependability to enumerate a sensor

- Dependability is a system property that integrates the following attributes -
  - Reliability - measure of continuous service accomplishments (measure 0 to infinity)
    - Mean-time-to-failure (MTTF)
    - Mean-time-to-repair (MTTR)
    - Mean-time-before-failure (MTBF)
  - Availability = MTTF / (MTTF + MTTR) ... (measure 0 to 1)
  - Safety, Security, Survivability, Maintainability – qualitative measure
- A structured view of dependability follows according to -
  - Threats (faults, errors, & failures)
  - Attributes (reliability, availability, ...)
  - Means for dependability (fault prevention, fault tolerance, fault removal, & fault forecasting

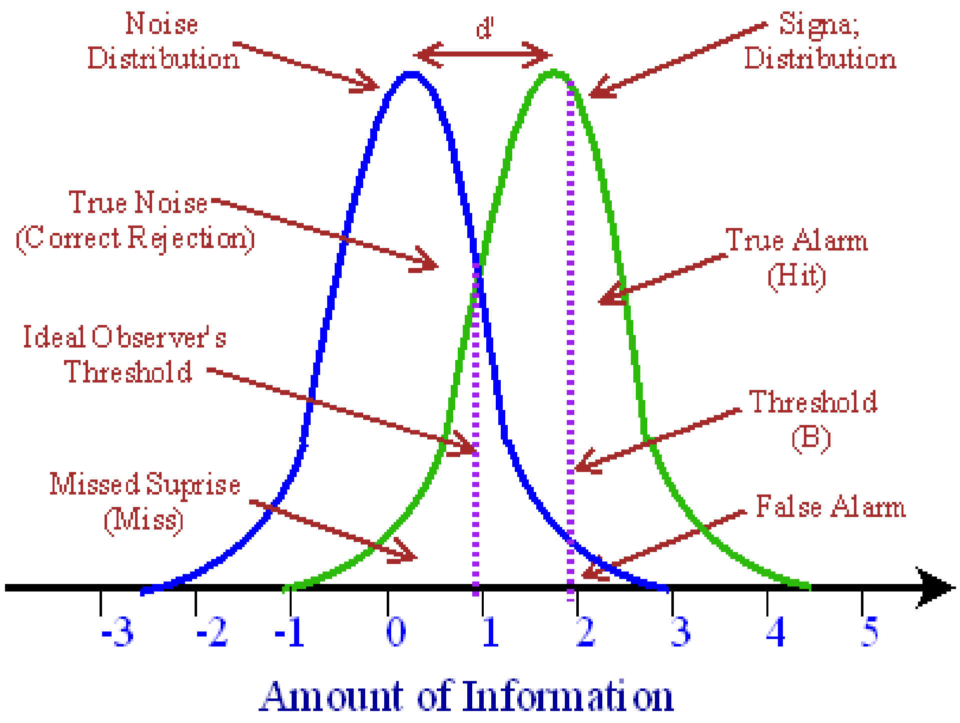
Sensor

# Evidence theory to enumerate a multi-sensors

- How do we know that the evidence from the sensors are true, especially when there are multiple sources with slightly different information?
- Probability requires that probabilities for all the events are available
- When not available apply uniform distribution function, justified by *Laplace principal for insufficient reasons*
- Uncertainty
  - *Aleatory* – inherent variation associated with physical systems or the environment (also known as variability, irreducible uncertainty, stochastic uncertainty, random uncertainty, or objective uncertainty)
  - *Epistemic* – due to lack of knowledge of properties or knowledge (also known as subjective uncertainty, reducible uncertainty, or ignorance)
- Evidence theory can correctly represent uncertainties from intervals, degrees of belief, and probabilistic information
- Apply Dempster-Shafer Theory (DST) as a framework to characterize uncertainty of sensor information and extend the theory to address combination of evidence

# Detection system

- Process of extracting a subset of information from a set of information
- how to analyse information in order to categorize ambiguous messages which can be generated from a known phenomenon
- Threshold:
  - Empirical – stimulus level allowing observer to perform a task
  - Theoretical – property of a model
- Goal of detection theory is to estimate two parameters from experimental data
  - *d′* - Strength of the signal (relative to noise)
  - *β* - Strategy of the response (i.e. easily saying yes rather than no)
- Detection system would develop some rules to match between the primary set of information and presented set of information
- Conditional probability in the signal detection paradigm




| | *Yes* | *No* |
|---|---|---|
| *Signal present* | Hit rate | Miss rate |
| *Signal absent* | False alarm rate | Correct rejection rate |

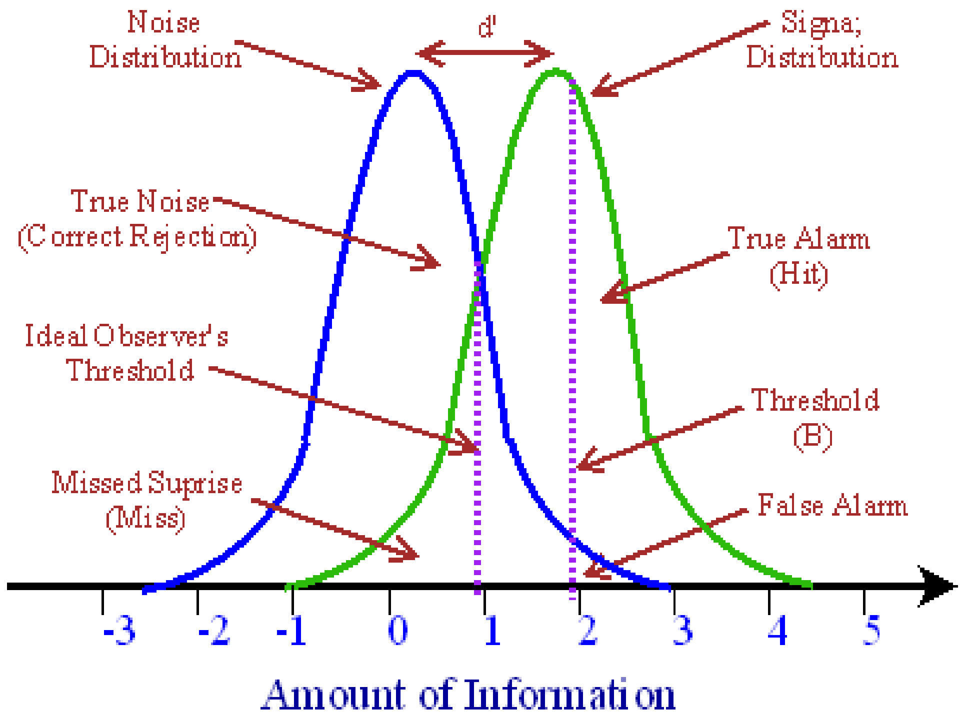
# Gherkin detection example

Good

Bad

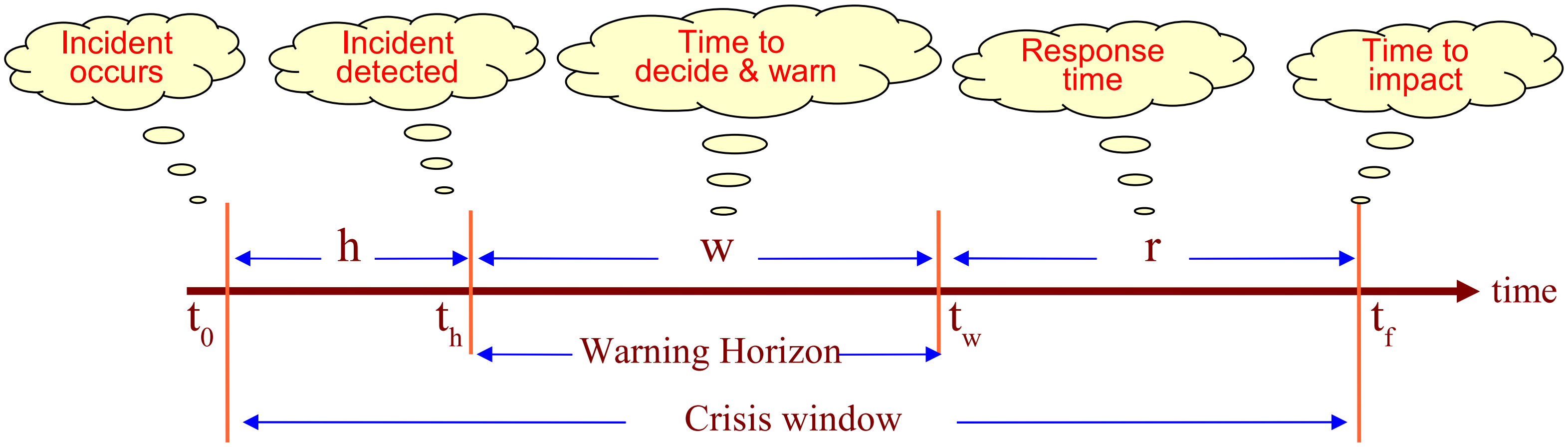
Stimulus

Traceability of Agriculture Markets,
photo by LIRNE*asia* and Flickr



Decision

# Decision system




- Goal of a decision system is to anticipate a crisis within the warning horizon time frame
- Variable of interest takes a value 1 at time ***t*** if a disturbance in physical world is detected within ***h*** length of window of crisis at hand
- To assess the adequacy of an EWS, probability forecasts are converted to event forecasts
- Low cut-off rate with long warning horizons are better for high risk-averse decision process since they lead to more system disturbance signals
- With long warning horizons there are less missed disturbances but there will be excessive false alarms
- Optimal decision system must first consider calibration issues of individual forecasting tools and explore several forecasting combination issues

Decision

# Measuring the decision process

- $x_{i,t-1}$ = available predictors at time $t-1$
- $y_{it} = f(x_{i,t-1})$; EWS-Indicator, a function of the available predictors
- $d_{i,t+k}$ = disturbance occurring within an $h$ length of window; $k$=0, 1, 2, ..., h
- $y_{it}$ = 1, if $d_{i,t+k}$ = 1 at any $k$=0, 1, 2, ..., h and 0 otherwise
- $\hat{y}_{it}$ = 1 is a forecast that a crisis will occur some time during [$t$+1 , $t+H$] for a particular value of $h = H$,
- $\lambda$ = threshold or cut-off probability, value set is domain specific, e.g. 0.25, 0.5, etc
- $\theta$ = cost attached to a miss crisis relative to a false alarm; e.g. 0.8 = ration 4 to 1
- $E_0(\lambda,h)$ = number of false warnings, $(\hat{y}_{it} = 1 | y_{it} = 0)$
- $E_1(\lambda,h)$ = number of missed disturbances, $(\hat{y}_{it} = 0 | y_{it} = 1)$
- $C_0(h)$ = total number of tranquil crisis $(y_{it} = 0)$
- $C_1(h)$ = total number of crisis $(y_{it} = 1)$
- $C = C_0 + C_1 = NT$; where $N$ is the number of crises and $T$ is the period
- $P_I = E_1(\lambda,h)/C_1(h)$; Type I error probability (percentage of missed crises)
- $P_{II} = E_0(\lambda,h)/C_0(h)$; Type II error probability (likelihood of a false alarm)

Decision

# Decision maker's Loss Functions

- Optimize the expected cost of mispredicitting
    - Type I errors (missed crisis) are a higher concern
    - Type II errors (false alarms) are a less concern
- Three main loss functions
    - *Noise-to-signal loss* – minimize the false to correct alarm ratio:
        - $NS(\lambda,h) = P_{II}(\lambda,h) / (1-P_{I}(\lambda,h))$; $NS \in [0,1]$
    - *Stakeholders' loss* – minimize cost of a Type I error relative to that of a Type II error
        - $SL(\theta,\lambda,h) = \theta P_{I}(\lambda,h) + (1-\theta)P_{II}(\lambda,h)$; $SL \in [0,1]$
    - *Policy makers' loss* – weighted sum of the miss disturbance and the probability of issuing a warning
        - $PL(\theta,\lambda,h) = \theta P_{I}(\lambda,h) + (1-\theta)PW(\lambda,h)$; $PL \in [0,1]$
        - $PW = Pr(\hat{y} = 1|y = 0)Pr(y = 0) + Pr(\hat{y} = 1|y = 1)Pr(y = 1)$

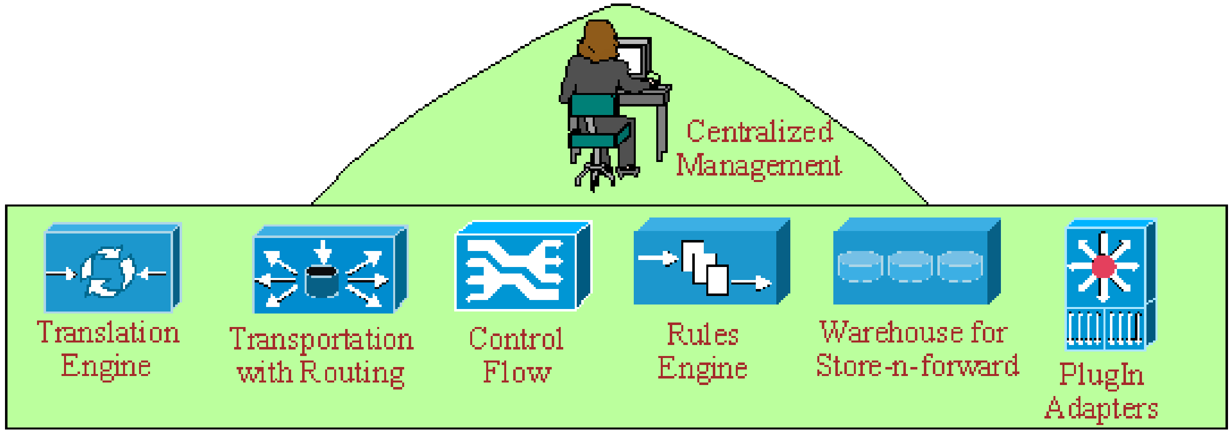
Decision

# Computational methods

- Enumeration method
  - *Logistic regression* – given a set of predictor (observer) variables, predict the probability that a certain crisis will occur during a given time horizon
  - *K-Means clustering* – partitioning data sets in to different subsets such that data in each subset share a common trait
  - Recursive tree analysis – represent the decisions and possible consequences, chances, outcomes, resource costs, and utilities with a graph
- Forecast combining – combine the information than opt for one of the alternatives

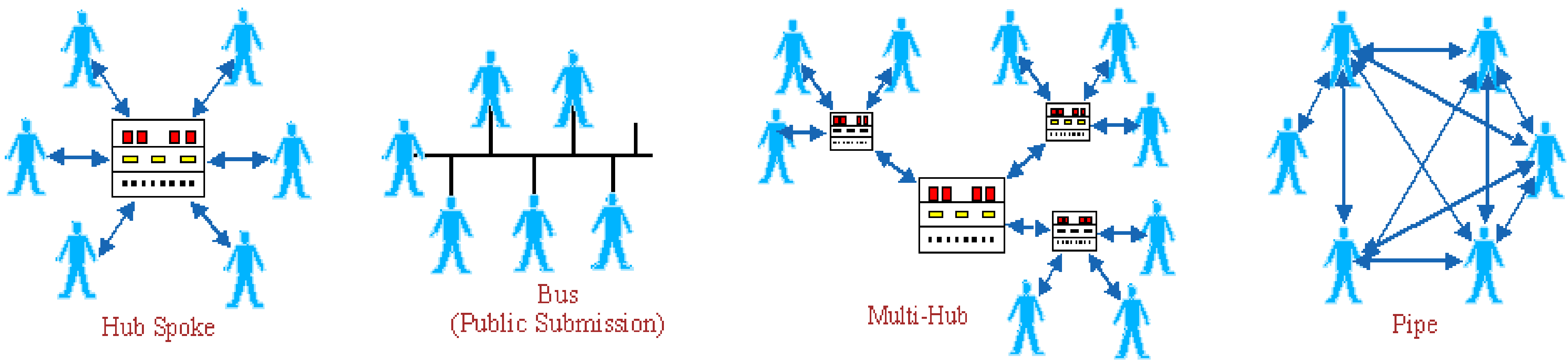
Broker

# Broker system




- Tasks of a broker

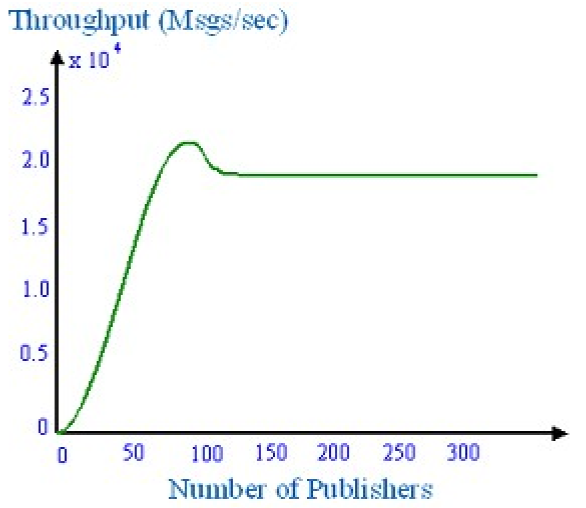
- Common topologies

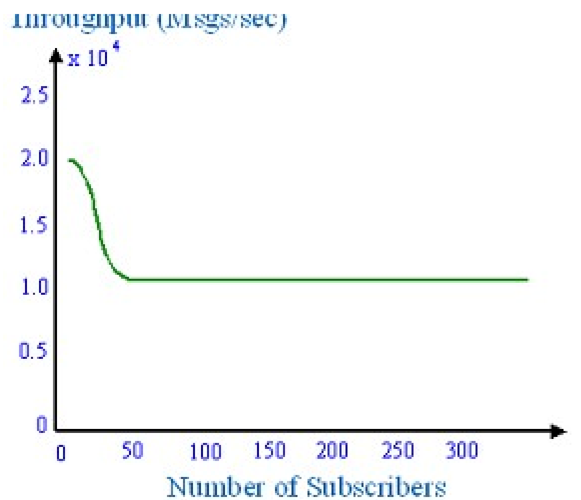


Broker

# Broker performance measures

- Throughput (efficiency) of the broker is common measure for all tasks
  - Bulk message sent in one-way
  - Bulk message round-trip
    - Same message is returned
    - Alteration of message is returned
- Other measures of tasks besides throughput
  - Translate – accuracy & conciseness
  - Transport – Number of routing calls, Maximum allowable payload, Quality of Service
  - Control – user security, information security, information flow (priority)
  - Rule – computational complexity
  - Warehouse – storage cost & available capacity
  - Adapt – scalability & dependability
  - Manage – outcome, output, cost, productivity




Mechanism for an abstract measure for broker system is an open problem

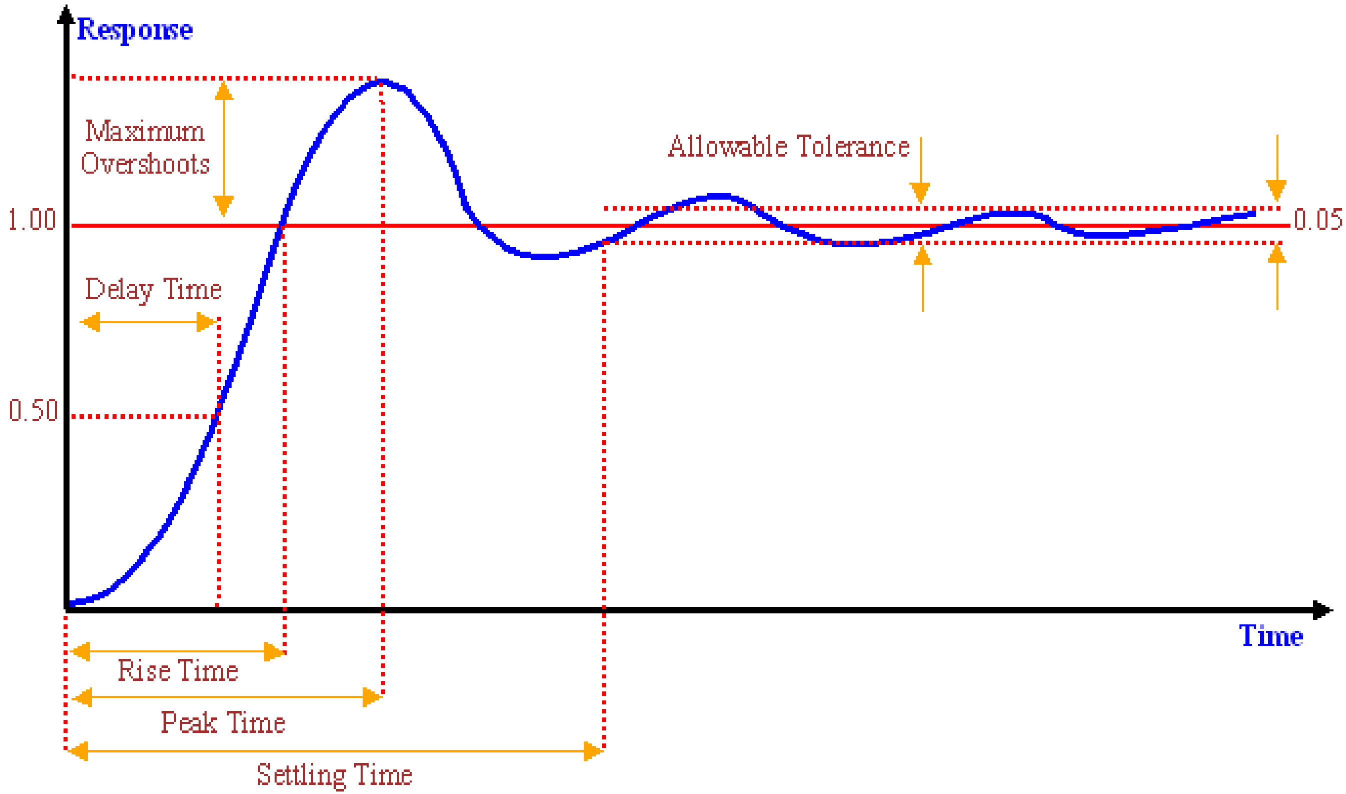
Response

# Response system

- Key component of an “effective” EWS
- Controlled variables in a system (physical world) is the quantity or condition that is measured and controlled
- Manipulated variables in a system is the quantity or condition that is varied by the responder (controller) so as to affect the controlled value
- First step in analysing a response system is deriving a mathematical model
- Analysis of the response system is done by applying various test inputs and comparing the behaviour of the response system with respect to the behaviour of the controlled system (physical world)

Response

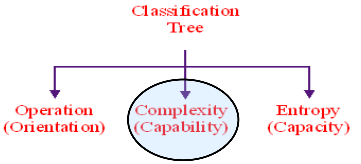
# Transient and Steady-state response




## Example

- Assume 3000 people
- 30 minutes to impact
- Rate 100 people per minute

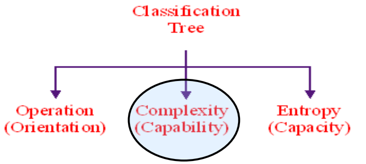
# What is Complexity



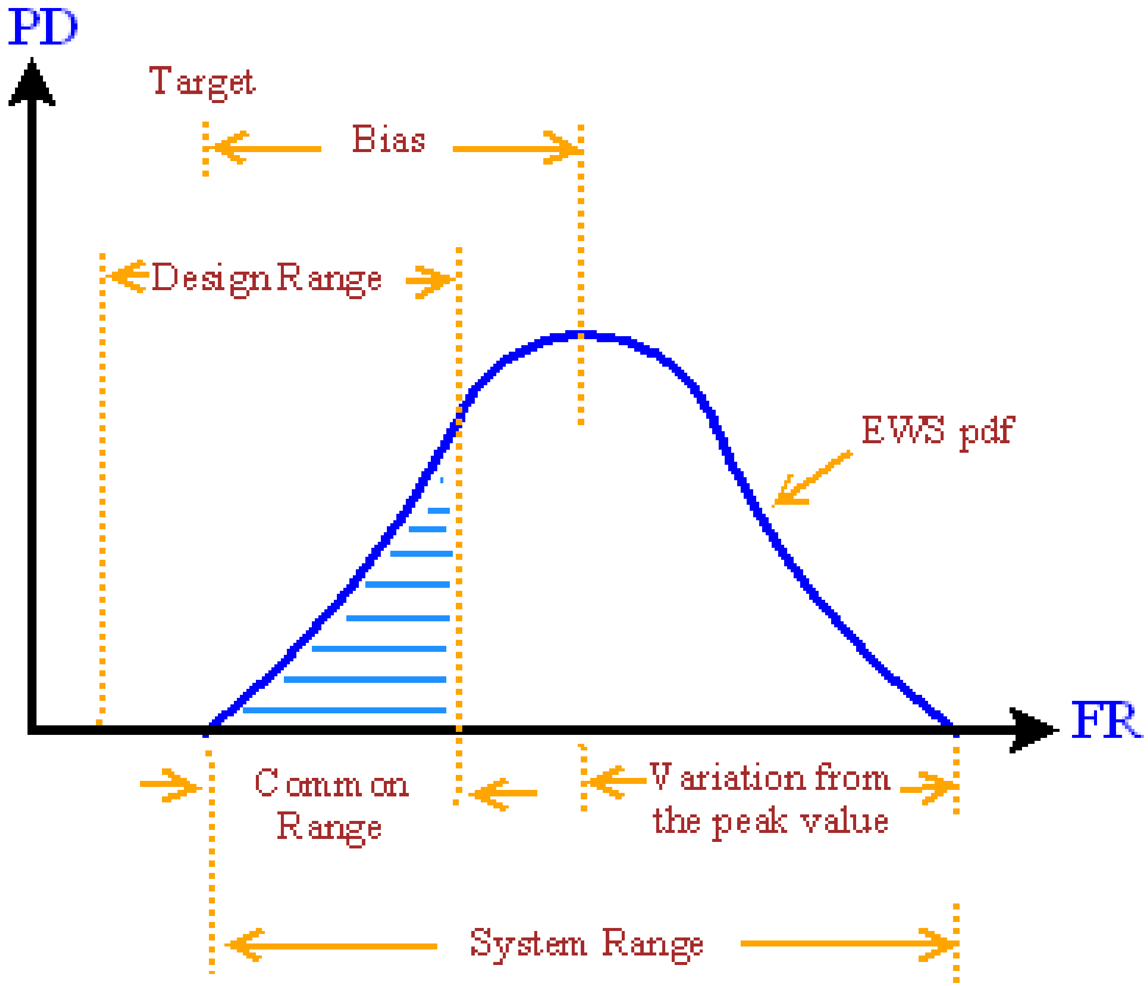

- Example: Fuel warning indicator vs Financial EWS
- "Complexity" a function of the relationship between the design range and the system range, which is affected by the relationship among the Functional Requirements (FR) – Suh 2005
- FR – "what we want to achieve"
- FR in EWS - is the function performed by the system to signal a disturbance in the physical world within the expected warning horizon in order to execute response actions for risk-aversion.
- DP – "how we are going to satisfy the FR"
- DP in EWS – the chain of communication systems: sensor, detection, decision, broker, response
- PV - "who will manipulate the DP and when do they do it"
- PV – Standard operational procedures

**Proposition**: EWS are Complex Systems

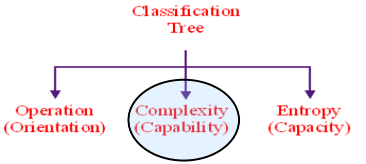
# Measuring Complexity



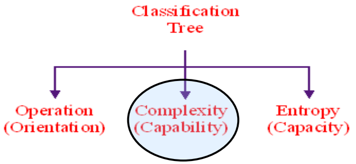

- ***Design range*** – specification of the desired value of the FR
- ***System range*** – probability distribution of the actual system chosen to satisfy the FR
- ***Common range*** – overlap of system range and design range indicating the finite certainty FR may be satisfied
- ***Target*** – system pdf should be equal to the target value inside the design range; i.e. Target and mean of system range must coincide
- ***Bias*** – the distance between the target and the mean; bias should be very small
- ***Variance*** – variability of the pdf caused by: noise, coupling, environment, & random variation



# Five types of complexities



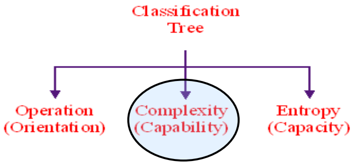

- Time independent (system range is static)
  - *1) **Zero*** – design range completely inside system range (opposed to infinite complexity when design is completely outside)
  - ***2) Real***
    - Relationship between DP and FR known
    - FR is satisfied in a specific order
    - Equal to the known information content of the system
    - Reduced by eliminating the bias and the system variance
  - ***3) Imaginary***
    - relationship between DP and FR unknown
    - Lack of understanding of system design, architecture, & behaviour
- Time dependent (system range is dynamic – drifts with time)
  - ***1) Combinatorial***
    - System range changes as function of time
    - system range drifts away from design range
    - physical phenomenon makes it difficult for the system to satisfy the FR
    - When the number of sequences increase combinatorially over time
  - ***2) Periodic***
    - when system undergoes periodic change
    - possible to make the system perform in a predictable way
    - Functional periodicity and not temporal



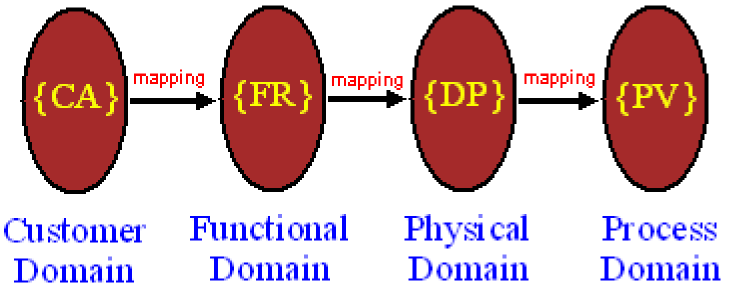

# Safety and Reliability of a System

1) Define FR and Constraints correctly
2) Make time-independent real complexities zero
3) Make time-independent imaginary complexities zero
4) After 1), 2), & 3) are satisfied eliminate time-dependent combinatorial complexity
5) Introduce time-dependent periodic complexity to reduce combinatorial complexity

# Axiomatic design framework




- Customer Attributes (CA): Need the customer is looking for
- Functional Requirements (FR): what is that we want
- Design Parameter (DP): How do we achieve it
- Process Variables (PV): who does what when and how




Example: TraceAM

FR: want to trace agriculture products

FR1: receive information

FR11: raw material usage

FR12: environmental threats

FR2: send information

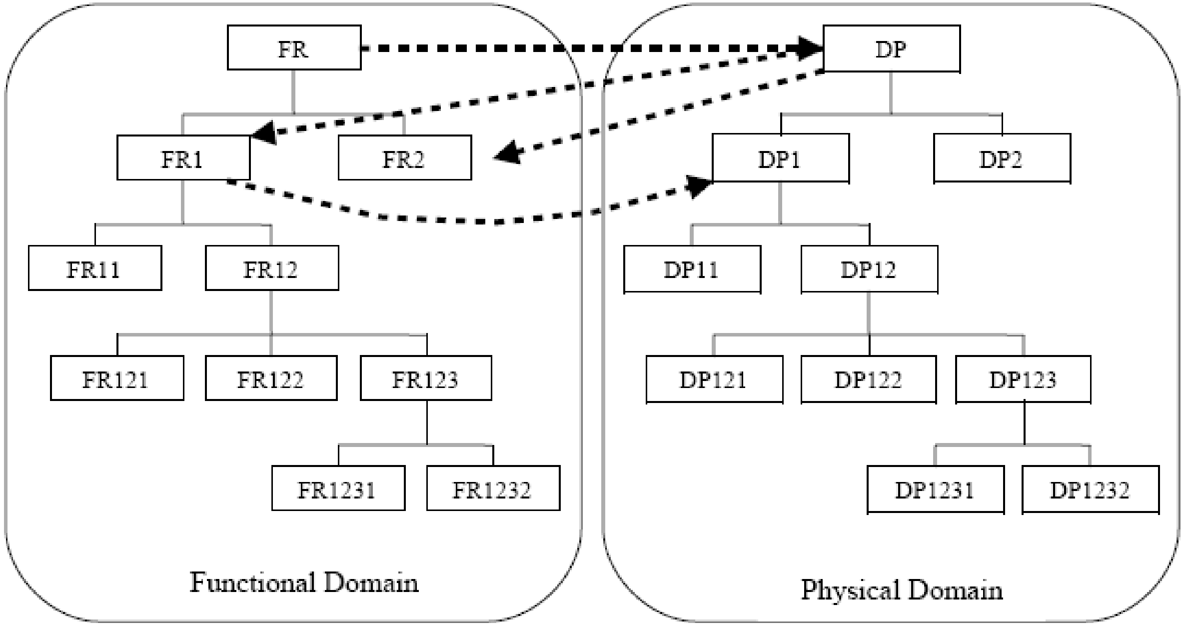
DP: achieve with ICT

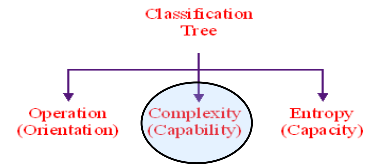
DP1: Upstream communication

DP11: raw materials database

DP12: threats database

DP2: Downstream communication






# Independence Axiom

- Axiom: maintain the independence of the FR
- Uncoupled

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} A_{11} & 0 & 0 \\ 0 & A_{22} & 0 \\ 0 & 0 & A_{33} \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix}$$

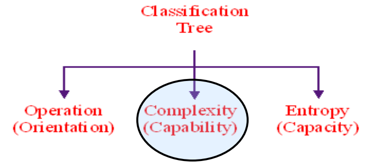
- Decoupled

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} A_{11} & 0 & 0 \\ a_{21} & A_{22} & 0 \\ a_{31} & a_{32} & A_{33} \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix}$$

- Coupled

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} A_{11} & a_{12} & a_{13} \\ A_{21} & A_{22} & a_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix}$$

# Example: Independence axiom - LM-HWS Sensor




**Customer attributes**

CA1 = establish trusted source to receive accurate hazard alerts in a timely manner

**Functional requirements**

FR1 = access to the World Wide Web
FR2 = access to voice, sms, and data services
FR3 = subscription to local and global hazard bulletin
- FR31 = sms bulletins
- FR32 = email bulletins
- FR33 = rss feeds

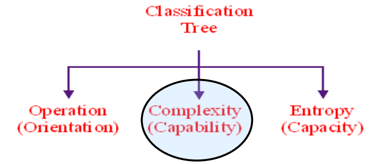
FR4 = monitor local and global hazard bulletins
FR5 = ensure all equipment are functional at all times
- FR51 = power surge protection
- FR52 = long term power failure backup plan
- FR53 = short term power failure backup plan

**Design Parameters**

DP1 = Internet Service Provider
DP2 = GSM service provider
DP3 = global disaster alerting systems
- DP31 = sms bulletins (GDACS)
- DP32 = email bulletins (GDACS, PTWC)
- DP33 = rss bulletins (USGS)

DP4 = PC connected to internet
DP5 = Uninterrupted power
- DP51 = UPS 0.6Kva
- DP52 = Diesel Generator
- DP53 = Solar power with battery

| | | DP1 | DP2 | DP3 | | | DP4 | DP5 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | DP31 | DP32 | DP33 | | DP51 | DP52 | DP53 |
| FR1 | | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| FR2 | | 0 | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| FR3 | FR31 | 0 | X | X | 0 | 0 | 0 | 0 | 0 | 0 |
| | FR32 | X | x | 0 | X | 0 | 0 | 0 | 0 | 0 |
| | FR33 | X | x | 0 | 0 | X | 0 | 0 | 0 | 0 |
| FR4 | | X | x | 0 | 0 | 0 | X | 0 | 0 | 0 |
| FR5 | FR51 | 0 | 0 | 0 | 0 | 0 | 0 | X | 0 | 0 |
| | FR52 | 0 | 0 | 0 | 0 | 0 | 0 | X | X | 0 |
| | FR53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | X |




# Information Axiom

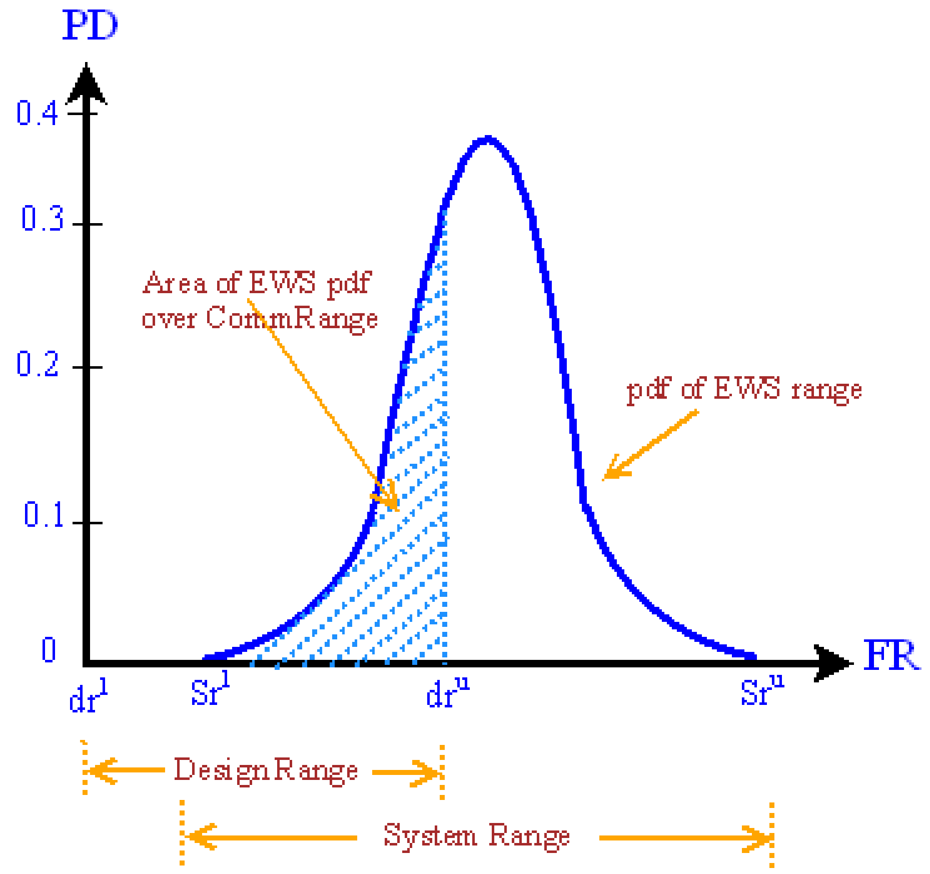
- Minimize the information content (design with the highest probability of success is best)
- Information is given in units of bits
- Information content $I_i$ for a given $FR_i$ is defined in terms of probability $P_i$ of satisfying $FR_{i}$:

$$I_i = -log_2 P_i$$

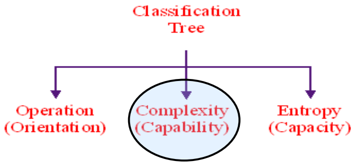
- Design's probability of achieving the overall goal; i.e. area of the common range = $A_{cr}$;

$$I = \sum I_i = -log_2 A_{cr}$$

- Quantitative measure of complexity is the information content (information content proportional to complexity)

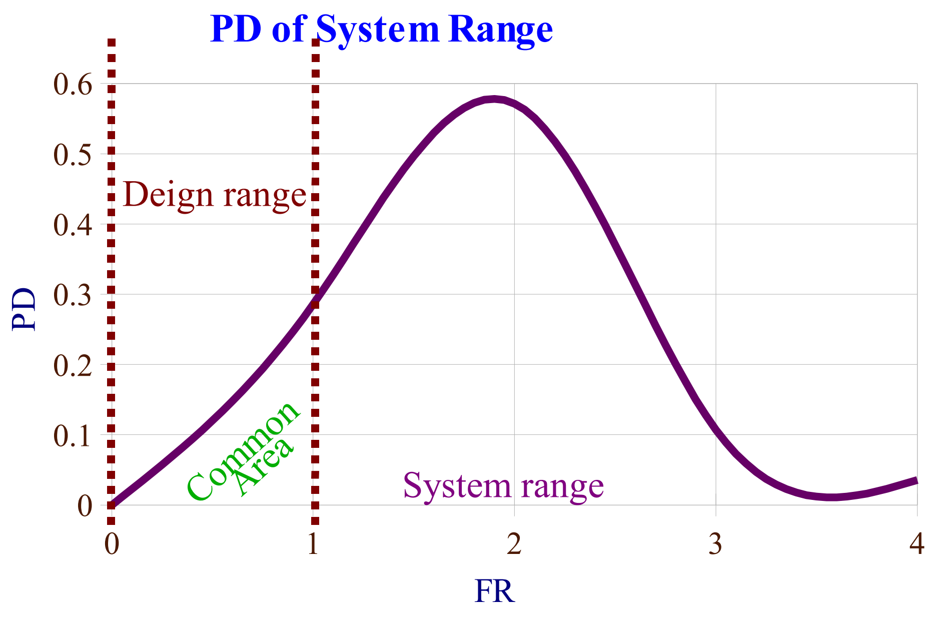


# Example: "Information Axiom" - LM-HWS Sensor system



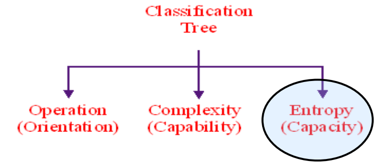

- FR = Receive email bulletin within 10 minutes of the incident
- DP = Google, GDAC, USGS, PTWC email alert
- Data from 28 email bulletins; difference between incident time and email received time

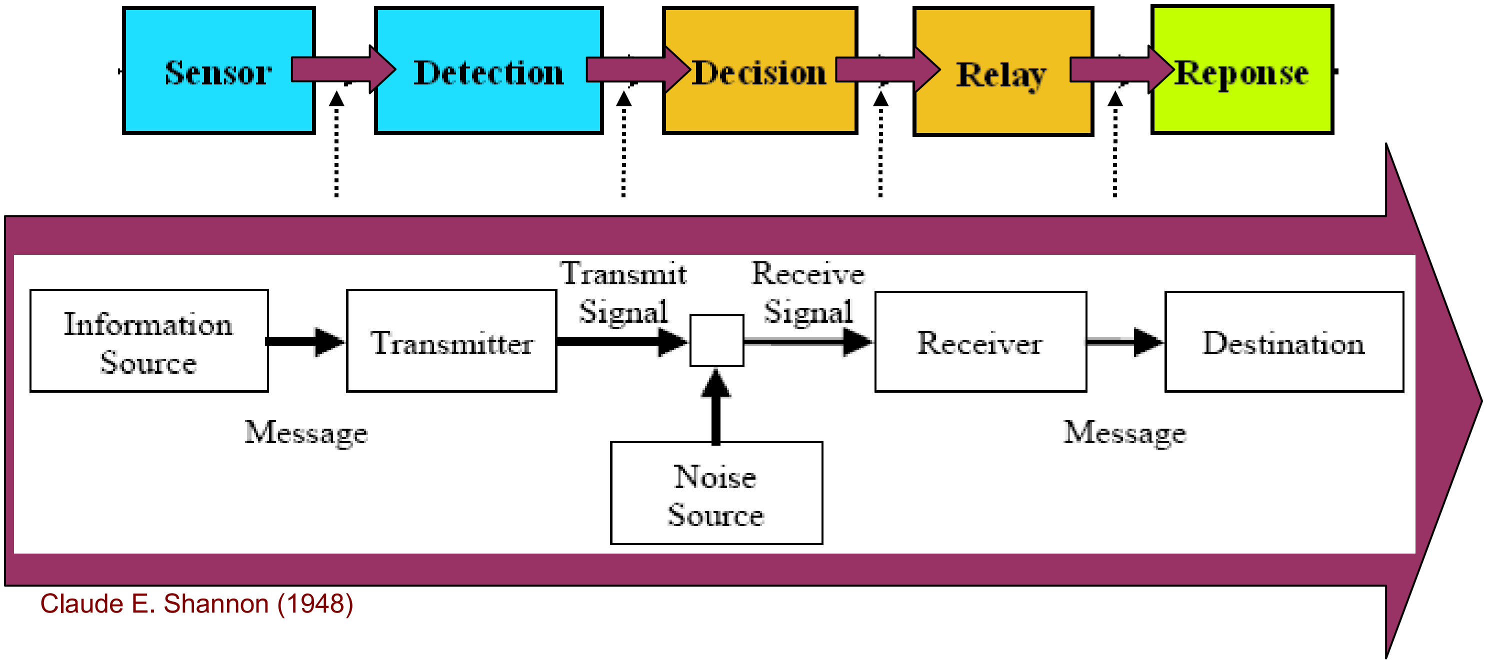
| Time Interval | T | 0 – 5 | 5 – 10 | 10 – 15 | 15 – 20 | 20 – 25 |
|---|---|---|---|---|---|---|
| Random Variable | X | 0 | 1 | 2 | 3 | 4 |
| Probability | P(X=x) | 0 | 0.29 | 0.57 | 0.11 | 0.04 |




$I = -\log_2 0.29 = 1.79$

# Chain of Communication Systems

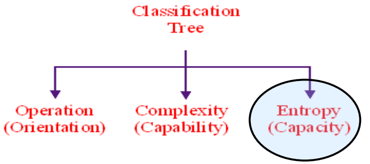


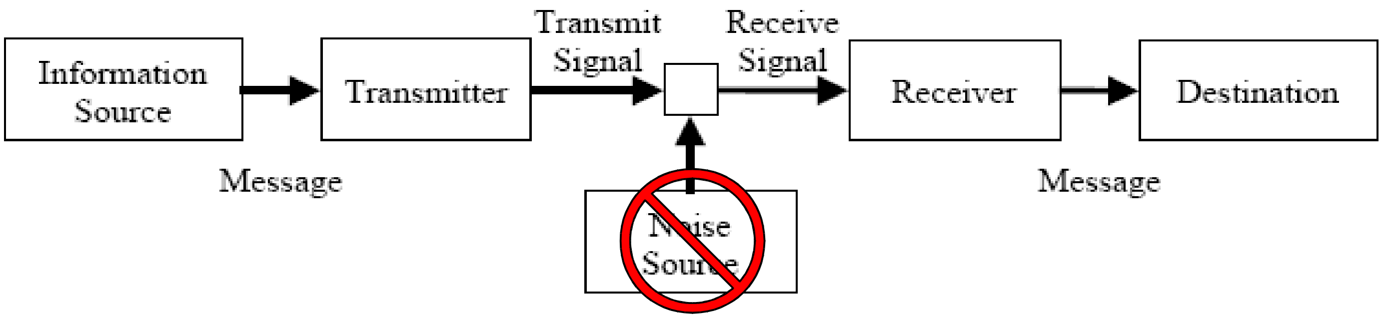




Claude E. Shannon (1948)

- ***Information source***: produces a message or sequence of messages
- ***Transmitter***: operates on the message to produce a signal suitable for transmission over a channel
- ***Channel***: a medium used to transmit the signal from transmitter to receiver
- ***Receiver***: performs the inverse operation of that done by the transmitter
- ***Destination***: person or thing the message is intended
- ***Noise source***: is a information source producing signals to agitate the transmit signal

# Fundamental Theorem of Noiseless Channels

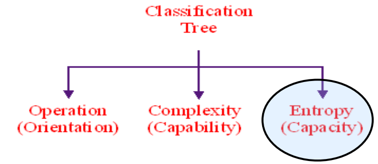


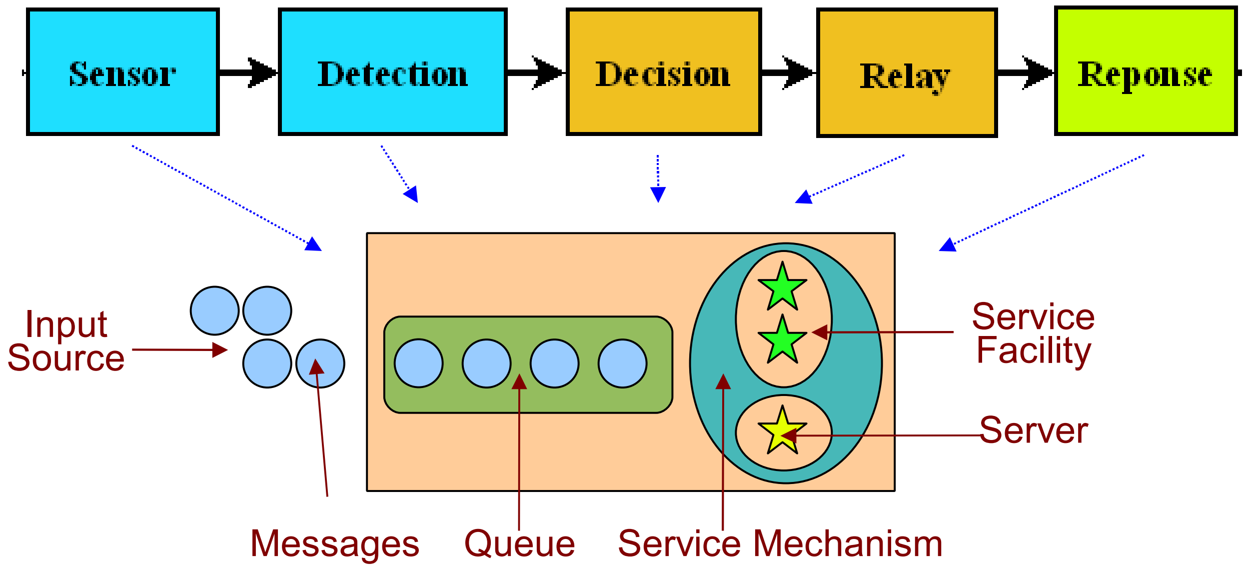




- "*Fundamental Theorem for Noiseless Channels*": Let a source have entropy ***H*** (bits per symbol) and a channel have a capacity ***C*** (bits per second). Then it is possible to encode the output of the source in such a way as to transmit at the average rate **C/*H* – *ε*** symbols per second over the channel where ***ε*** is arbitrarily small. It is not possible to transmit at an average rate greater than ***C/H*** (*Claude Shannon, 1948*).
- Example:
  - SMS symbols (characters) use UTF-8 (8 bit per character)
  - SMS channel can transmit 184 bits in 235.5 ms = 184/0.2355 = 781.31 bits per sec
  - ***C/H*** = 781.31/8 = 97.66 (symbols/sec)
  - ***C/H* - *ε*** = 97 symbols per second
  - SMS page with 140 characters (symbols) = 140/97 = 1.44 seconds
  - How long will it take to transmit a SMS txt-msg from one mobile phone to another mobile phone?

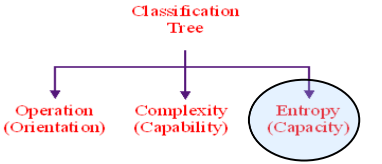
**Proposition**: "*EWS Communications Channels are Noiseless*":Channels between any two consecutive subsystems in the EWS chain of communication systems are noiseless channels; where underlying technology handless the noise.

# Basic Structure of a queuing model

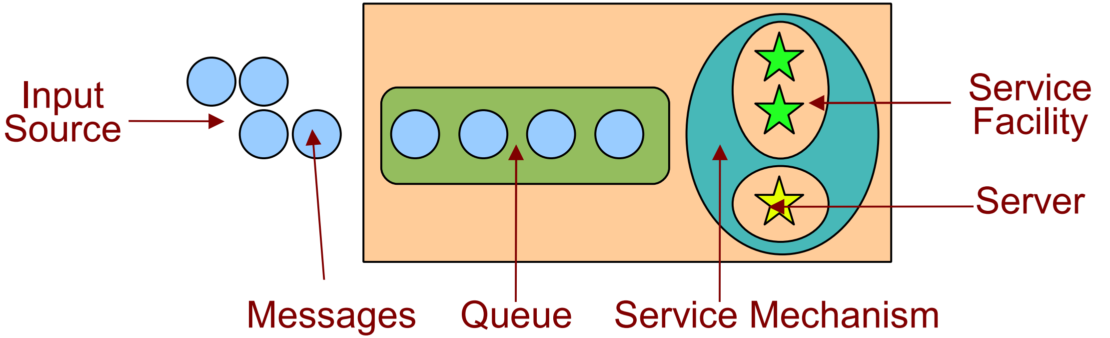



- Input source – generates events (messages) over time
- Queue – maximum permissible quantity of messages in a system
- Queuing system – places information received through input is placed in a queue
- Queue discipline – messages are selected processing based on a set of rules
- Service mechanism – performs operations on the queue discipline selected messages
- Server – single service channel that performs an operation on a message
- Service facilities – collection of servers with same operation
- Inter-arrival time – time between consecutive messages joining the queue
- Service time – elapsed time between operation commencement and completions

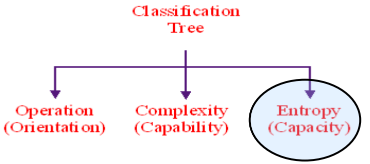



# Elementary queuing process




- Statistical pattern over which messages are generated must be specified, **common assumption is Poisson Process** (i.e. inter-arrival times are a Poisson distributions)
- Many such models assume that the inter-arrival times and service times are **identically distributed**
- Conventional labelling method: inter-arrival PD / service time PD / number of servers
- Example – $M / E_k / 2$ = Markov (exponential) PD / Erlang (shape parameter $k$) / 2 servers

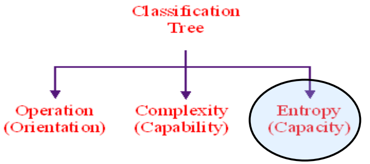
**Proposition**: "EWS queuing model":EWS queuing models are of elementary type; where messages are formed in a single queue that may be operated on by one or more servers.




# Standard terminology and notation

- State of System = quantity of messages in a queue
- Queue length = quantity of messages waiting to be served
- $N(t)$ = quantity of messages in queue system at time $t \geq 0$
- $P_n(t)$ = probability of exactly n quantity of messages in queue system at time $t \geq 0$
- $s$ = number of parallel server channels in queue
- $\lambda_n$ = mean arrival rate when $n$ quantity of messages are in queue
- $\mu_n$ = mean service rate for overall system when $n$ quantity of messages are in queue
- $\rho = \lambda / s\mu$ = utilization factor of the service facility
- $\mathcal{W}_q$ = waiting time in queue (excluding service time)
- $W_q = \mathrm{E}(\mathcal{W}_q)$ expected waiting time
- $L_q = \lambda W_q$ expected queue length (excluding messages being serviced)
- $\mathcal{W}$ = waiting time in the system for each individual message
- $W = E(\mathcal{W}) = W_q + 1/\mu$ expected waiting time for an individual message
- $L = \lambda W$ expected quantity of messages in queuing system (Little's formula)

# Properties of Exponential Distribution




- $T$ = random variable of inter-arrival or service times (completion of an arrival or service occurrence is referred to as an event)
- $\alpha$ = parameter of the exponential distribution with random variable $T$
- $f_T(t) = e^{-\alpha T}$ for $t \geq 0$ and 0 otherwise; probability density function (PDF)
- $P(T \leq t) = 1 - e^{-\alpha T}$ and $P(T > t) = e^{-\alpha T}$; cumulative probability
- $E(T) = 1/\alpha$; expected value of $T$
- $var(T) = 1/\alpha^2$; variance of $T$
- Property 1: $f_T(t)$ is a strictly decreasing function
- Property 2: Lack of memory
- Property 3: The minimum of several independent exponential random variables has an exponential distribution
- Property 4: Relationship to the Poisson distribution $\boldsymbol{P(X(t)=n) = (\alpha t)^n e^{-\alpha t}/n!}$; $n = 0, 1, 2 \ldots$
- Property 5: For all positive values of t, $P(T \leq t+\Delta t \mid T > t) \approx \alpha t$; for small $\Delta t$
- Property 6: Unaffected by aggregation or disaggregation

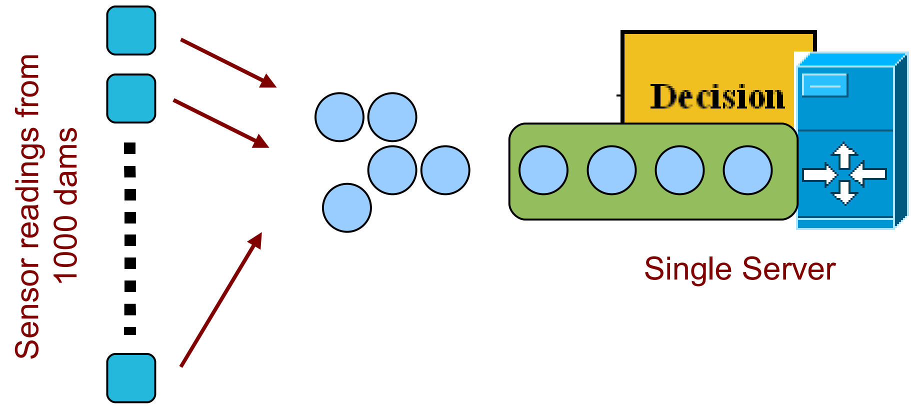
# Example: Dam-FEWS Decision System Queuing Model

Zipingpu dam Dujiangyun,
photo by NPR

**Meteorologic**
- rainfall

**Hydrological**
- water level
- sediment/debris

**Structural**
- seepage
- vibration
- pressure
- temperature
- moisture




- Rainfall during rainy season is in random intervals and random rates
- Data arrive according to an exponential PD (slow when drizzles starts high when it pours)
- Queue discipline for each data set = LIFO
- $T_i$ for $i$ = 1, 2, ... represent the random variable for each dam
- Expected inter-arrival time $E(T_1)$ = 5 minutes; therefore parameter $\alpha = 0.2$
- Probability that 2 messages will arrive in 5 minutes: $P(X(5) = 2) = (0.2*5)^2 e^{-0.2*5}/2! = 0.18$
- Probability that 0 messages will arrive in 5 minutes: $P(X(5) = 0) = (0.2*5)^2 e^{-0.2*5}/0! = 0.36$
- Assume the algorithm takes 0.25 minutes (15 sec) to update the status of a single dam
- Assume optimal conditions only 20 dams are actively being processed and are in the queue
- Given $P(X(5){=}0) = 0.36$, the waiting time for a single dam to be updated, in the worst case scenario, is 20*0.25 = 5 minutes

# Summary

- Operations (orientation & components)
  - Relate EWS to an observer-controller (predictor-corrector)
  - Necessary and Sufficient Components: sensor, detection, decision, broker, & response
  - Discuss methods for measuring the performance of the components
- Complexity (measure the system capability)
  - Apply axiomatic design framework to decompose the EWS
  - Establish the type of complexity of the EWS (zero, real, imaginary, combinatorial, or periodic)
  - measure the system capabilities using the independence axiom and information axiom; use the methods for measuring the individual component performance to determine the probabilities of the design matrix
- Entropy (Expected State)
  - Measure the entropy of the chain of communication system connecting the components
  - Apply queuing theory to measure the waiting time of a message for each component
- Classify EWS in terms of – operation / complexity / expected state

# Future Work: 5 year plan

- Complete the Theoretical framework (year 1 & 2)
  - Establish axioms and prove the theorems
  - Prove chosen primary classification parameters are orthogonal
  - Set-up guidelines for applying the classification scheme
  - Publish theoretical framework in academic journals
- Test Classification scheme through academics and practitioners (year 2, 3, & 4)
  - Select real world implementations in each domain
    - Financial
    - Dam
    - Tsunami
    - Agriculture
    - Health
    - Engineering
    - etc
  - Classify selected cases
  - Compare and contrast between similar cases (decomposition and composition)
- Dissemination (year 4 & 5)
  - Peer reviewed publications
  - Book for academics and practitioners
  - Promote scheme as a standard