Quantitative Risk Assessment

Kendrick Glenn
Michael Jansen
Oscar Gutierrez
OH3/ Assessments, Cost Estimates & Schedules Office (ACES)
August 27th, 2015

JSC Strategic Plan

- **Strategy 3.1 Lead through innovative technical and business management practices Success Factors:**
  - Aggressively pursue innovative technical and business approaches that drive affordability, sustainability, and accountability
  - Develop a customer-focused approach, streamlining policies, processes, and requirements such as agreements, pricing, and intellectual property to meet internal/external stakeholder needs
  - Promote the development of business acumen and situational awareness
  - Develop and implement an investment plan that provides critical capabilities while reducing infrastructure costs and meeting green technology goals
  - Emphasize life-cycle affordability and risk-informed decision processes in Program / Project management

QRA Defined

- **The Quantitative Risk assessment (QRA) is an objective risk assessment tool used to project threat impacts**
- **The QRA provides an estimate of the magnitude of consequences for each identified budget threat**
- **The estimated costs to the program are summarized into a total probabilistic budget threat estimate**
  - An estimate is derived using a range of values rather than a single value
  - An estimate can be a range of possible costs from a range of possible values; meaning the cost will fall within the estimated range
- **QRA systematically determines the likelihood of threats occurring and evaluates the cost (cents/$) of the occurrence**
- **QRA sets out to *define, measure, predict, and provide a confidence level of likelihood and occurrence of threat impacts***

Risk Defined

- **Any risk consists of 3 questions:**
  - What can happen?
    - Captured by risk identification and description
  - How likely is it to happen?
    - Represented by probability of occurrence
  - What is the impact if it did happen?
    - Described by cost impacts and uncertainty around the impacts

- **ISSP Risk Scorecard Definition:** A future event with a negative consequence that has some probability of occurring. An item whose resolution is unlikely without focused management attention.

- **Wikipedia Definition:** Risk assessment is a step in a risk management procedure. Risk assessment is the determination of quantitative or qualitative value of risk related to a concrete situation and a recognized threat (also called hazard). ***Quantitative risk assessment requires calculations of two components of risk (R):, the magnitude of the potential loss (L), and the probability (p) that the loss will occur.***

" There are risks and costs to a program of action. But they are far less than the long-range risks and costs of comfortable inaction. "
John F. Kennedy

Risk Measuring

- Explicit recognition of possible outcomes
- Highlight key factors (major drivers)
- Decision analysis involves selecting among alternatives
- A risk analysis of any particular decision tries to establish the range of outcomes for each decision that could occur were that decision taken
- The overall aim of risk analysis is to make better decisions; there is a link to optimization – we are aiming to select best decision

Risk Acceptance

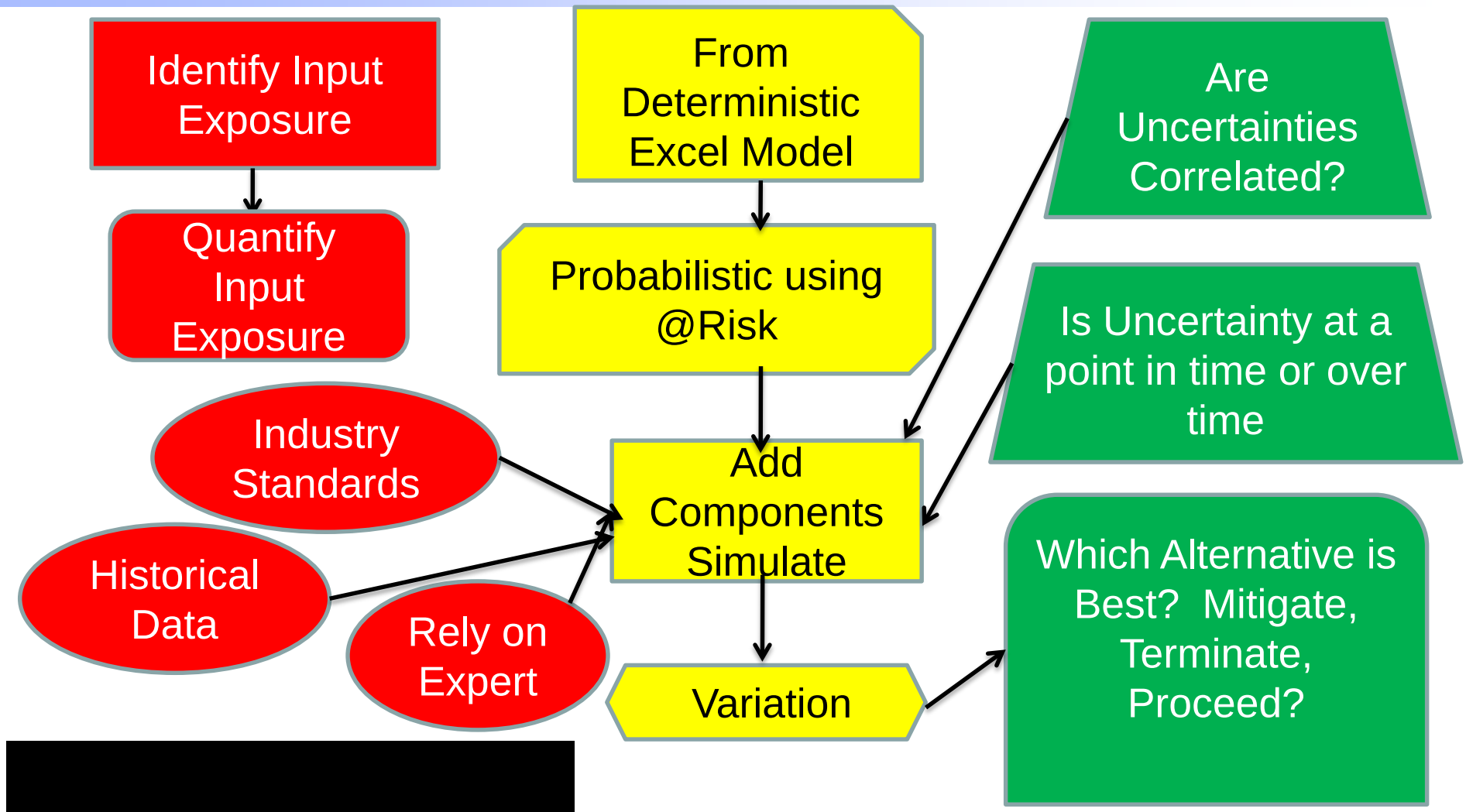
- Similarities between road trip and 100M mission
- Mitigation measures

[redacted]

[redacted]

"Only those who dare to fail greatly can ever achieve greatly."
Robert F. Kennedy

Stop and Go



[redacted]

Hunger Pains

- **Let us reflect on the saying: *"A Bird in the hand is worth two in the bush"***
- **The expected value of a decision does not incorporate any information about our attitudes to possible outcomes**
- **We might prefer the bird in the hand if we are really hungry (even if we think that there is a 99% chance of catching each bird, we might be too hungry to take the risk) and this is the only bush in the world.**
- **We might prefer the birds in the bush if:**
  - *We are not particularly hungry and we believe the probability of catching each bird is 50% or more*
  - *We are not hungry and we enjoy trying to catch birds whatever the probability is!*
- **Practical Example:**
  - *Select a project with lower average value than one with a higher average value if the latter project has some possible outcomes which are very poor*
- **Certainty v. Expectation**

Satisfied Customer

- **Bird In Hand: 100% Satisfies Risk. Extremely averse to uncertainty.**

- **Two Birds in Bush:**
  - Ammunition – Option to buy more (buy down, eliminate)
  - Marksmanship – Practice (buy down)
  - Environment – No control over (Accept as is)

"Only those who dare to fail greatly can ever achieve greatly."
Robert F. Kennedy

Monte Carlo History

- Thomas Bayes and French Mathematician Pierre-Simon Laplace
- Stanislaw Ulam and John von Neumann

"View of Monte Carlo (and Monaco) from the east" Hampus Cullin

"Take risks: if you win, you will be happy; if you lose, you will be wise."
Author Unknown

The Monte Way

- Evolve “point estimate” spreadsheets into modeling tools that process combinations of variables and thereby facilitate more robust analysis
- Recognize risk and uncertainty, and understand variability through simulation
- To capture the effect of changes to the inputs, especially in contexts where traditional sensitivity analysis is weak:
- To capture relationships between variables
- Valuation of contract clauses and contingencies
- Fair price for a game involving uncertain rewards

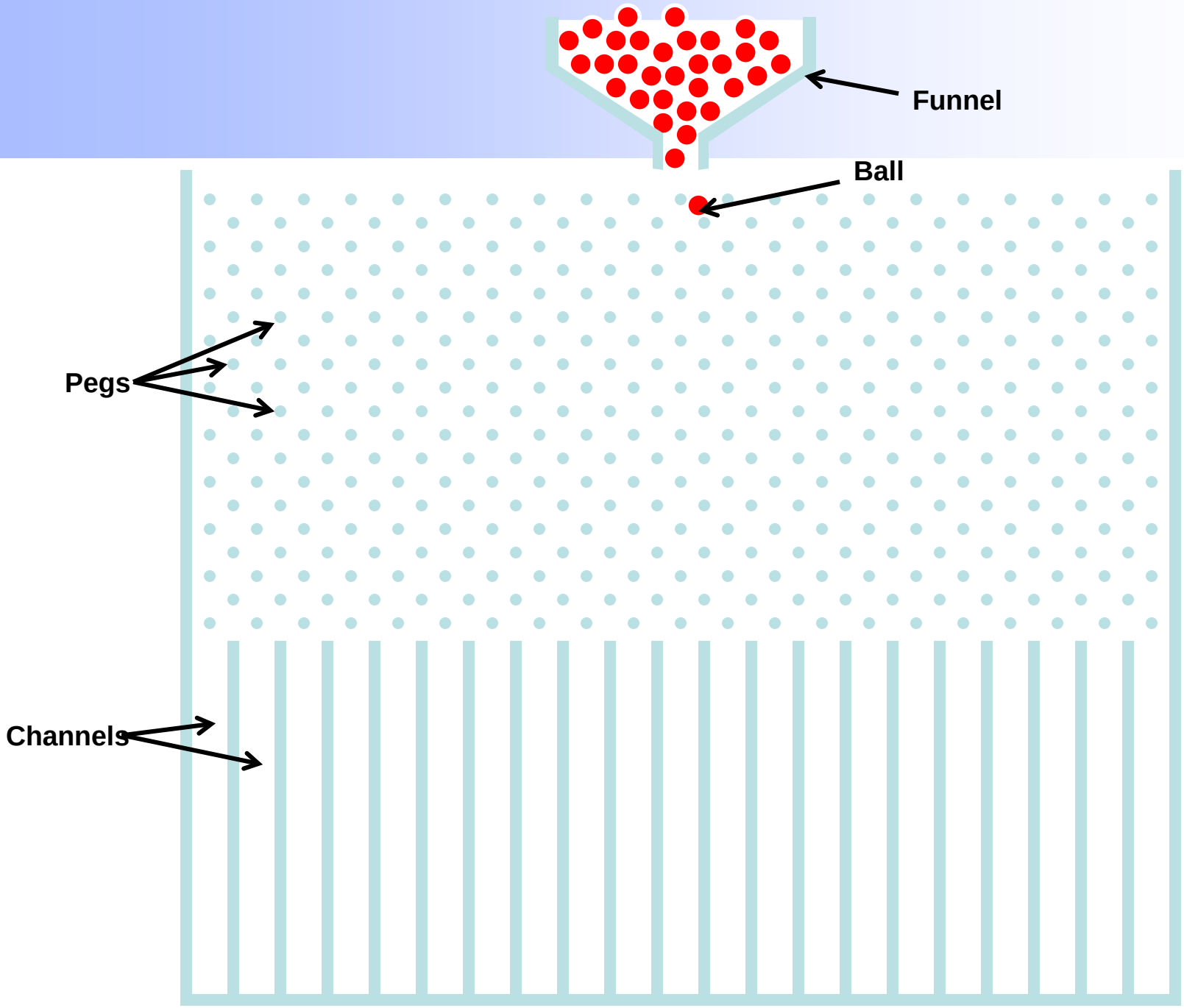
Casino de Monte-Carlo

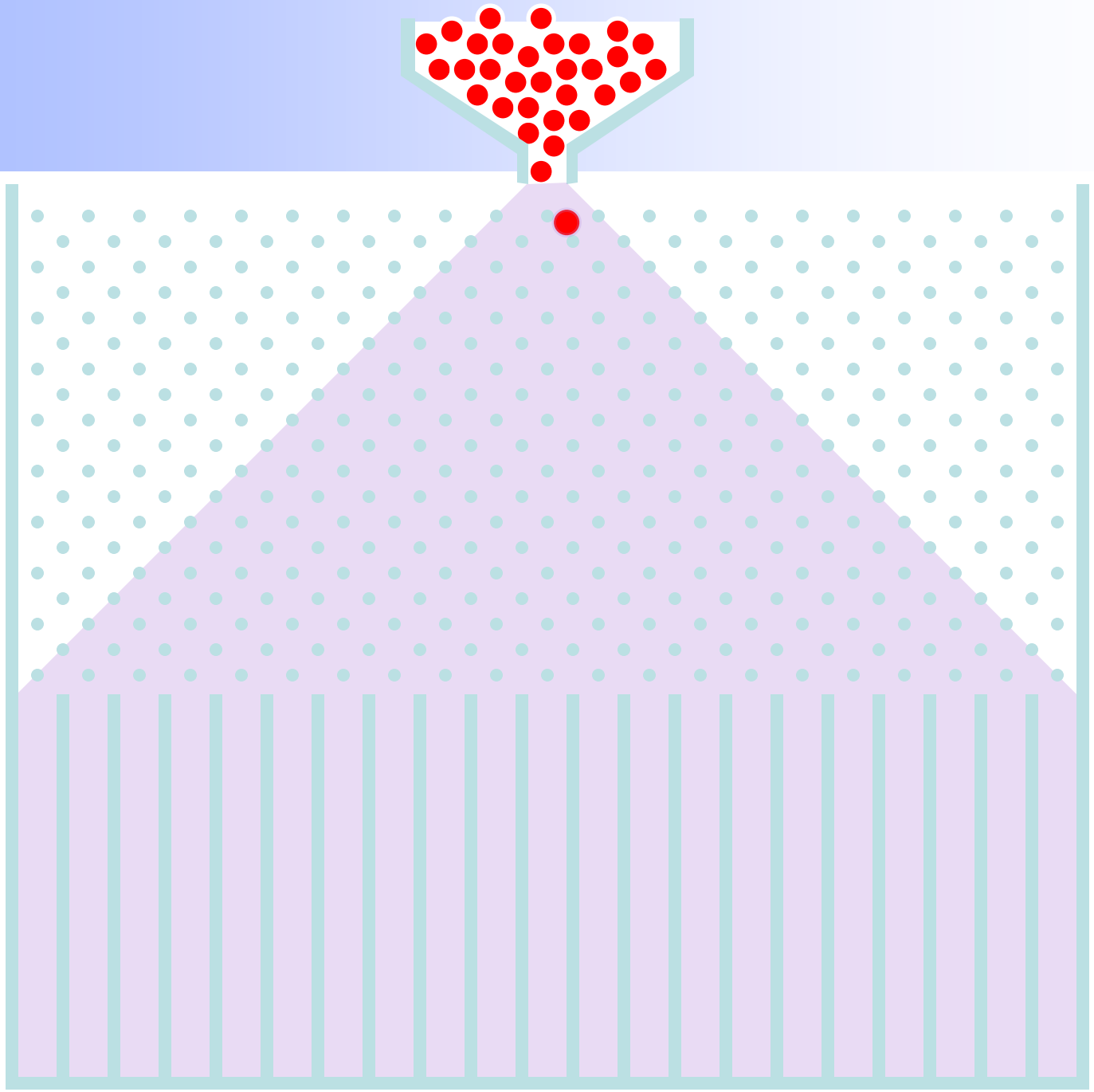
Sampling

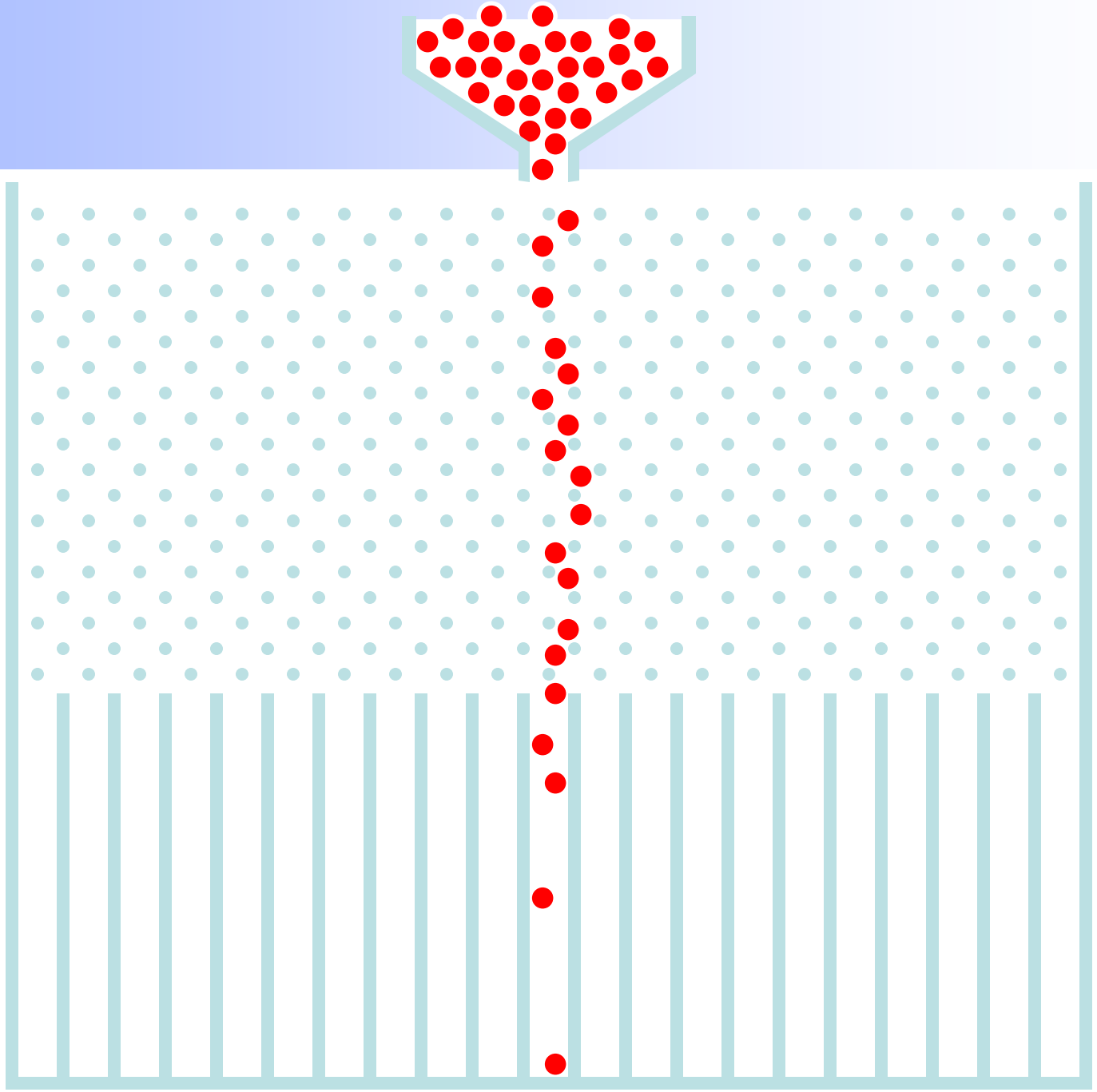
- **No. of Iterations: Rule of Thumb**
  - *Rapid convergence to reasonable accuracy with small number of iterations*
  - *Inverse square root law: doubling the accuracy requires four times as many iterations*
- **Convergence monitoring possibilities**
  - *Display updates*
  - *Manual and automatic convergence monitoring*
- **Sampling Type**
  - Monte Carlo = simple random number sampling
  - Latin Hypercube = intervals of equal probability

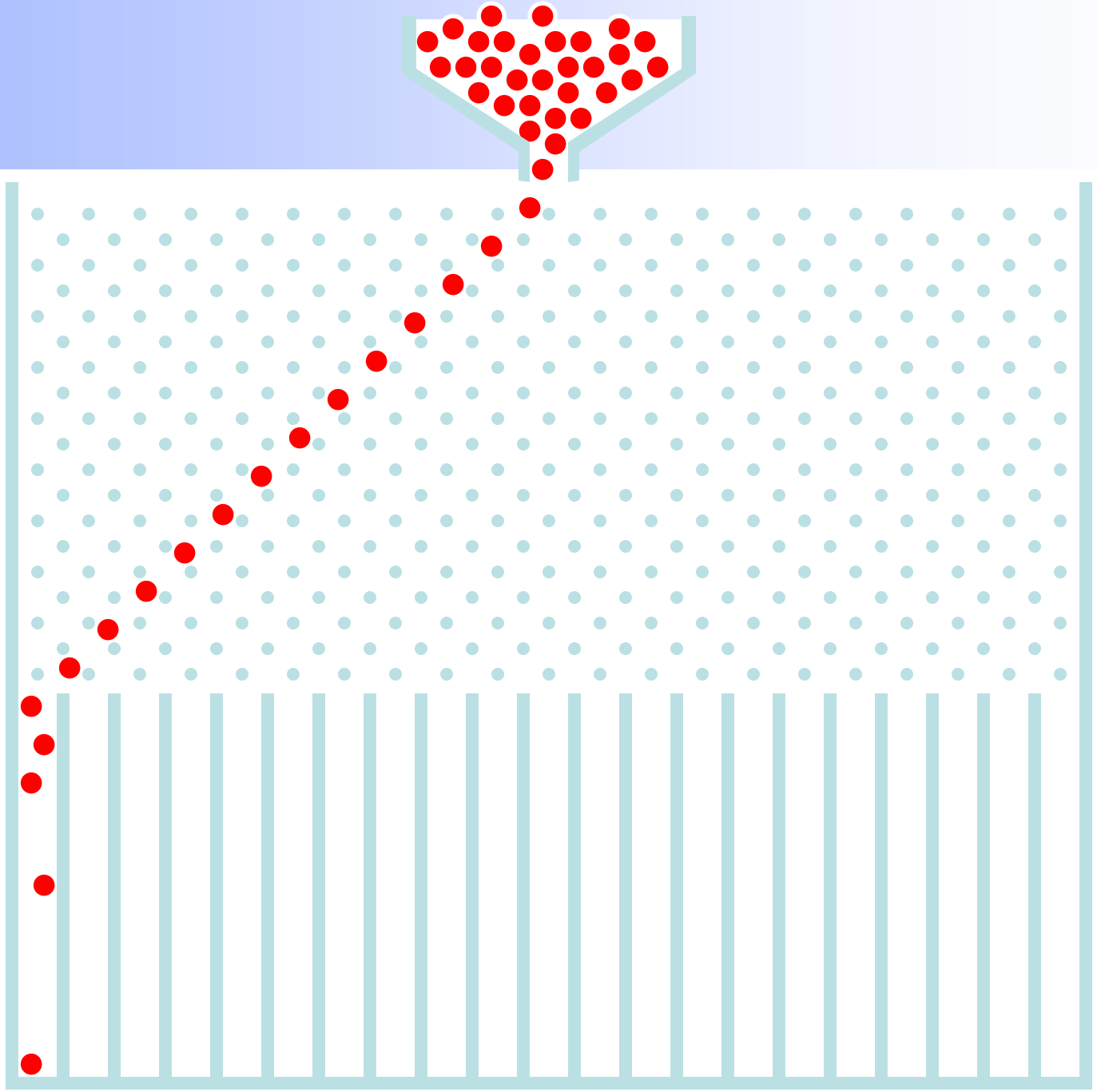
- **Randomness is a way to try to achieve results without creating a biased sample**

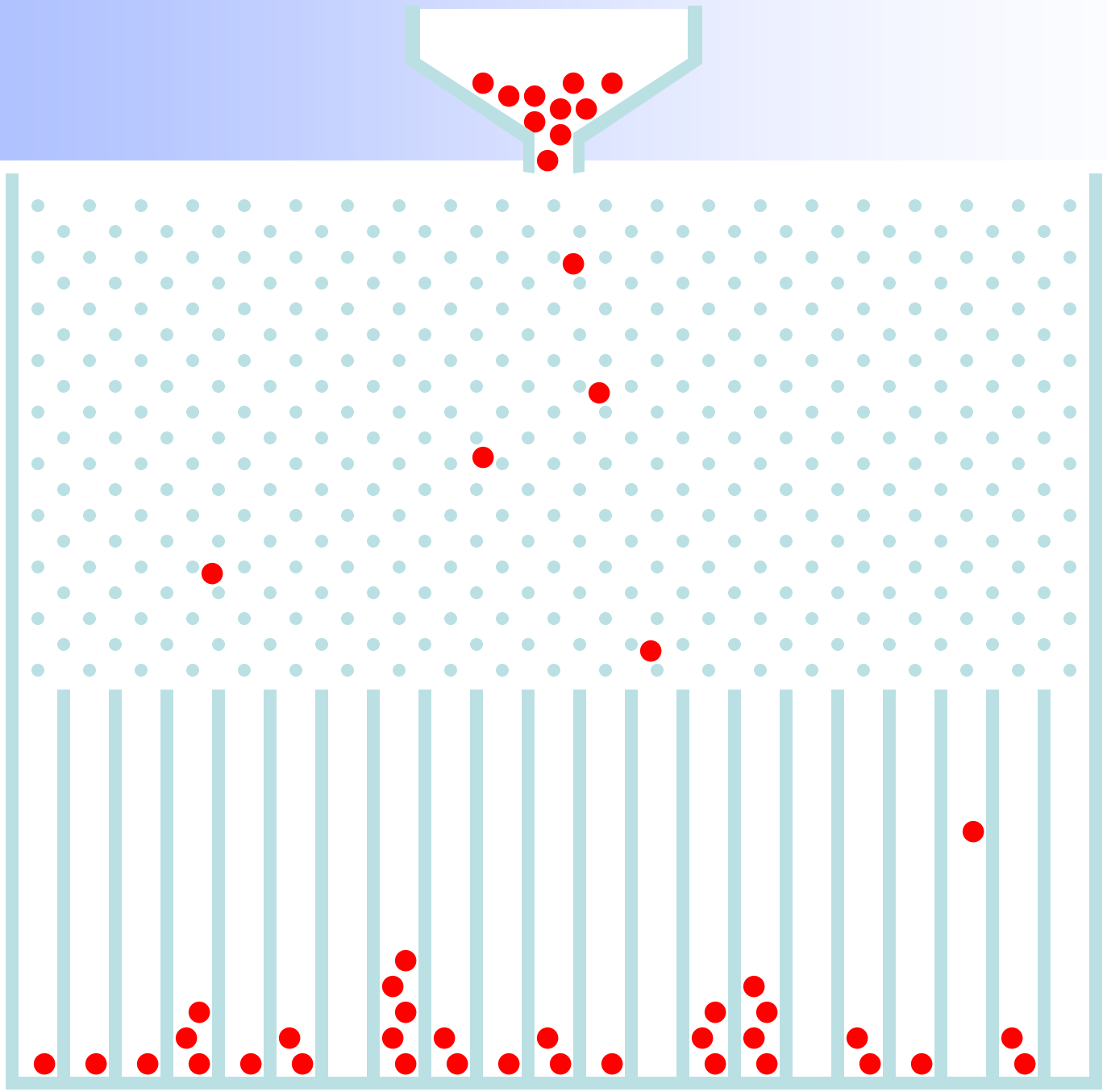
PLINKO

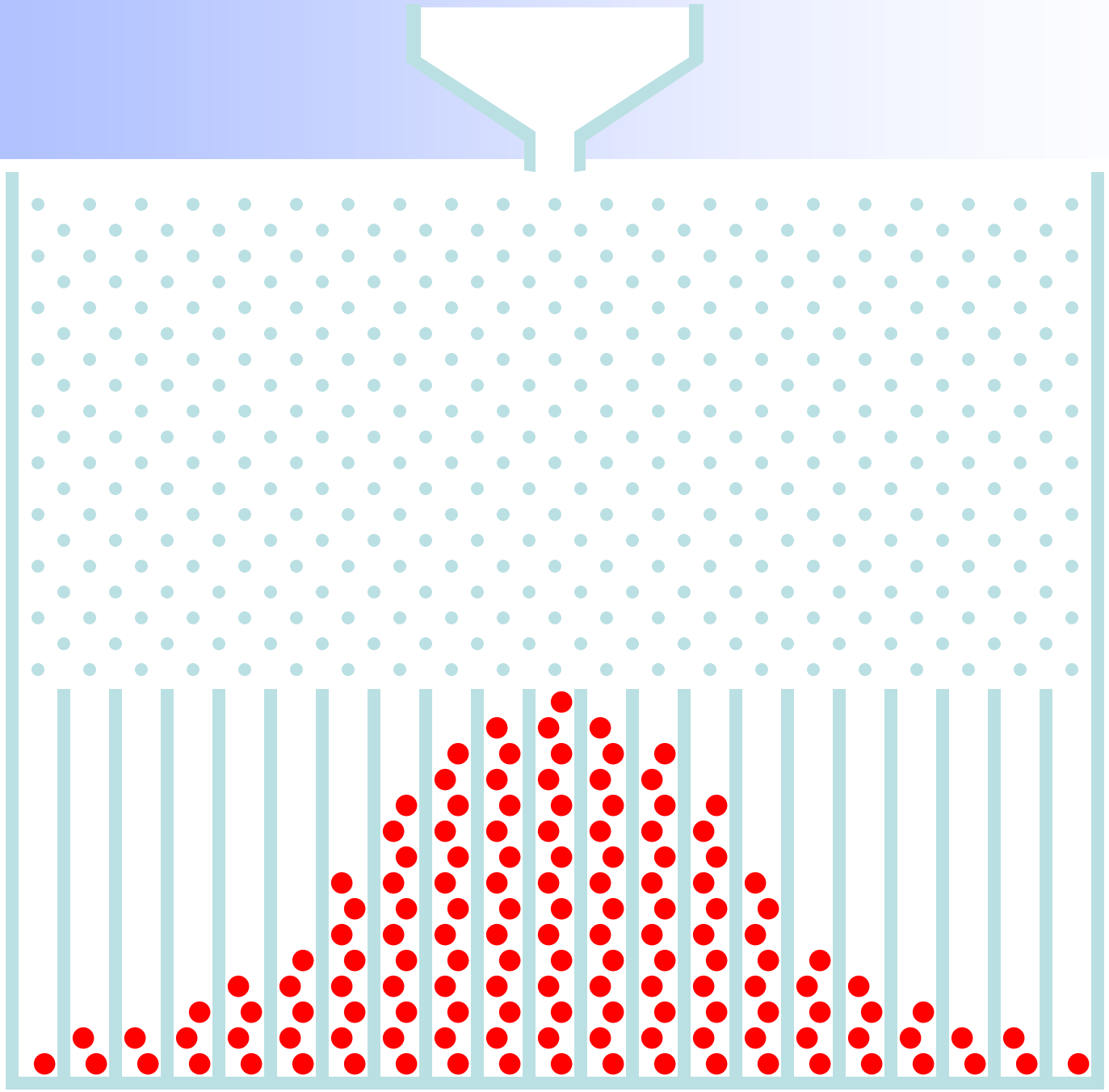

Funnel
Ball
Pegs
Channels

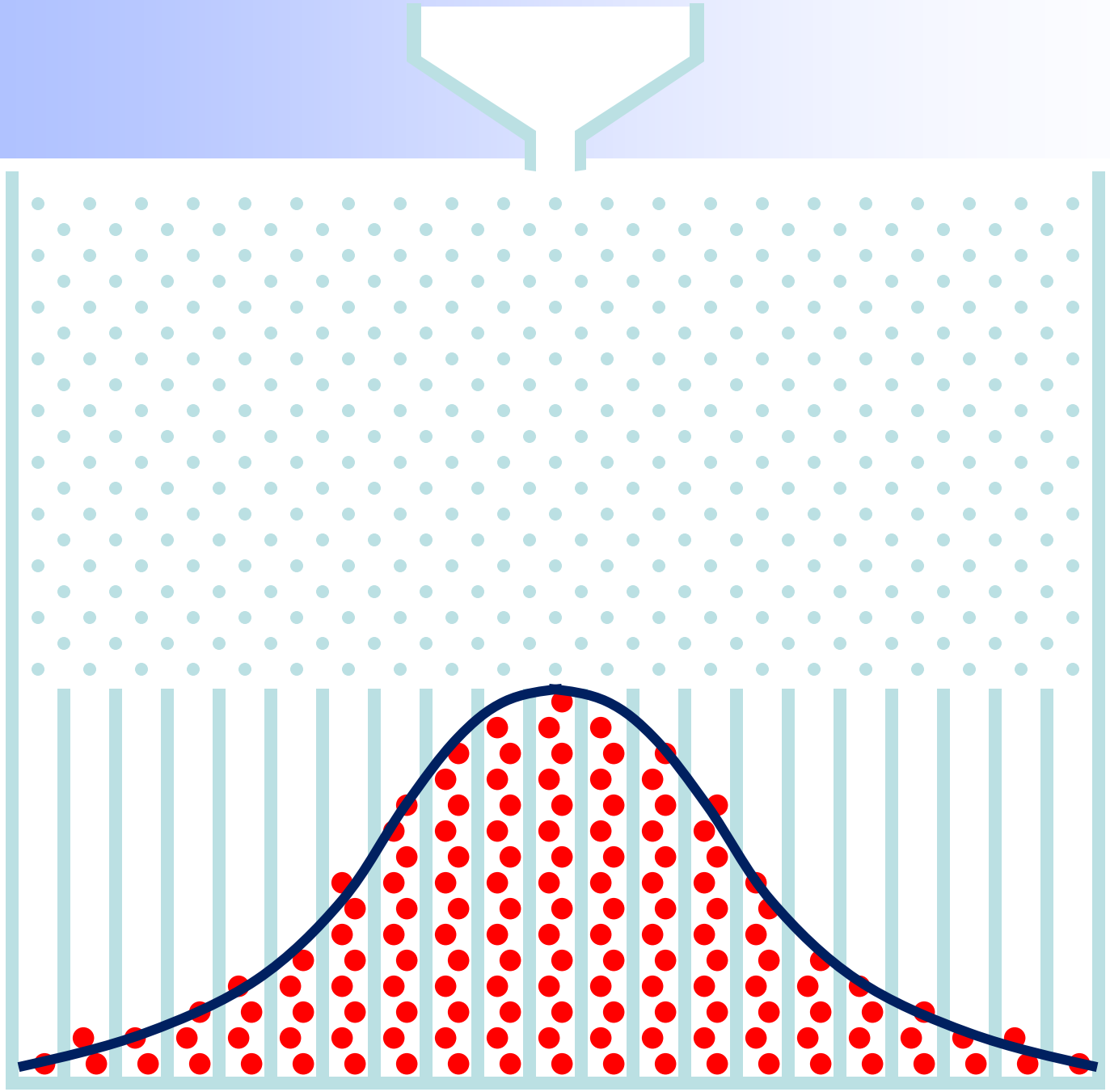


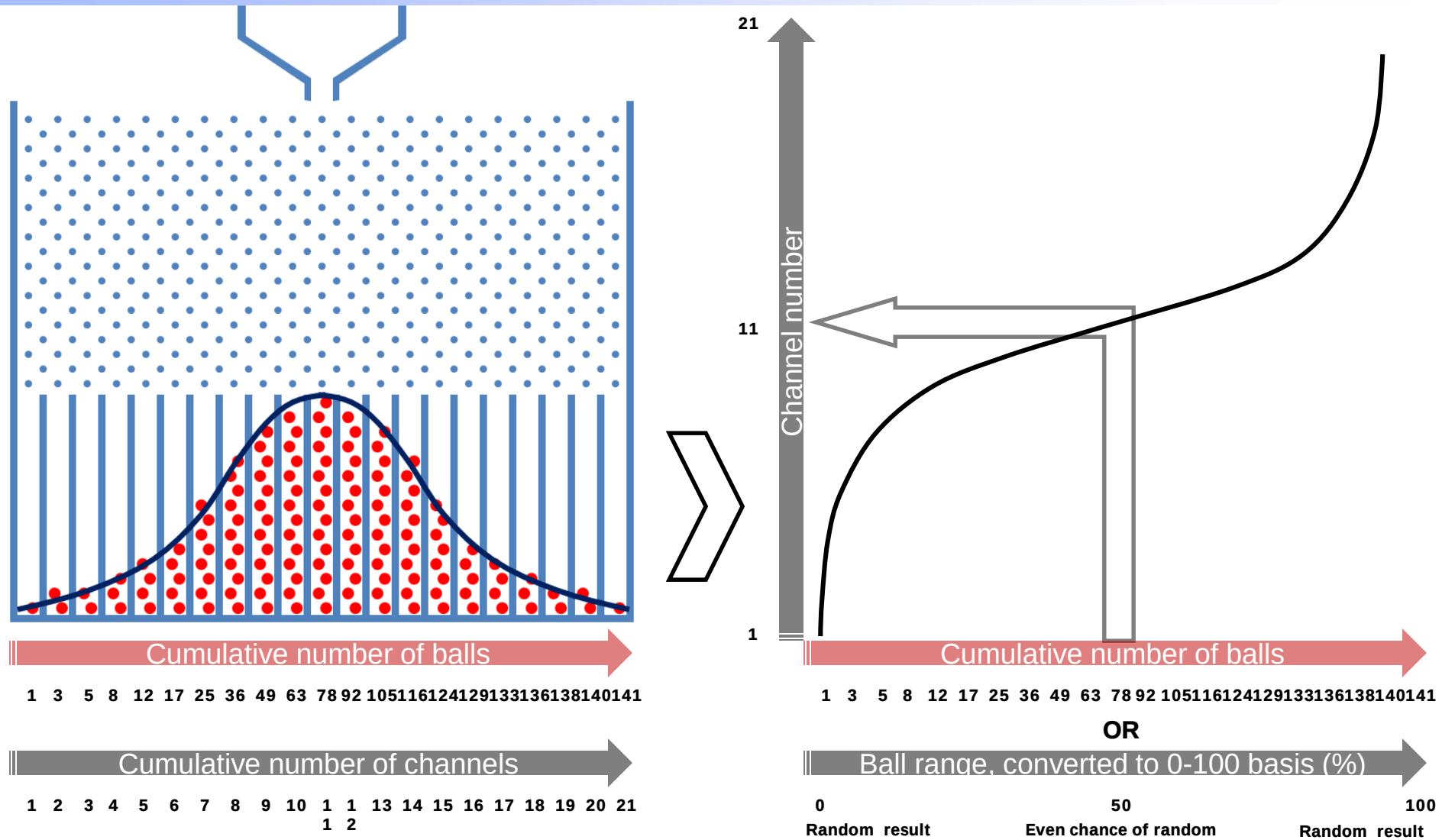


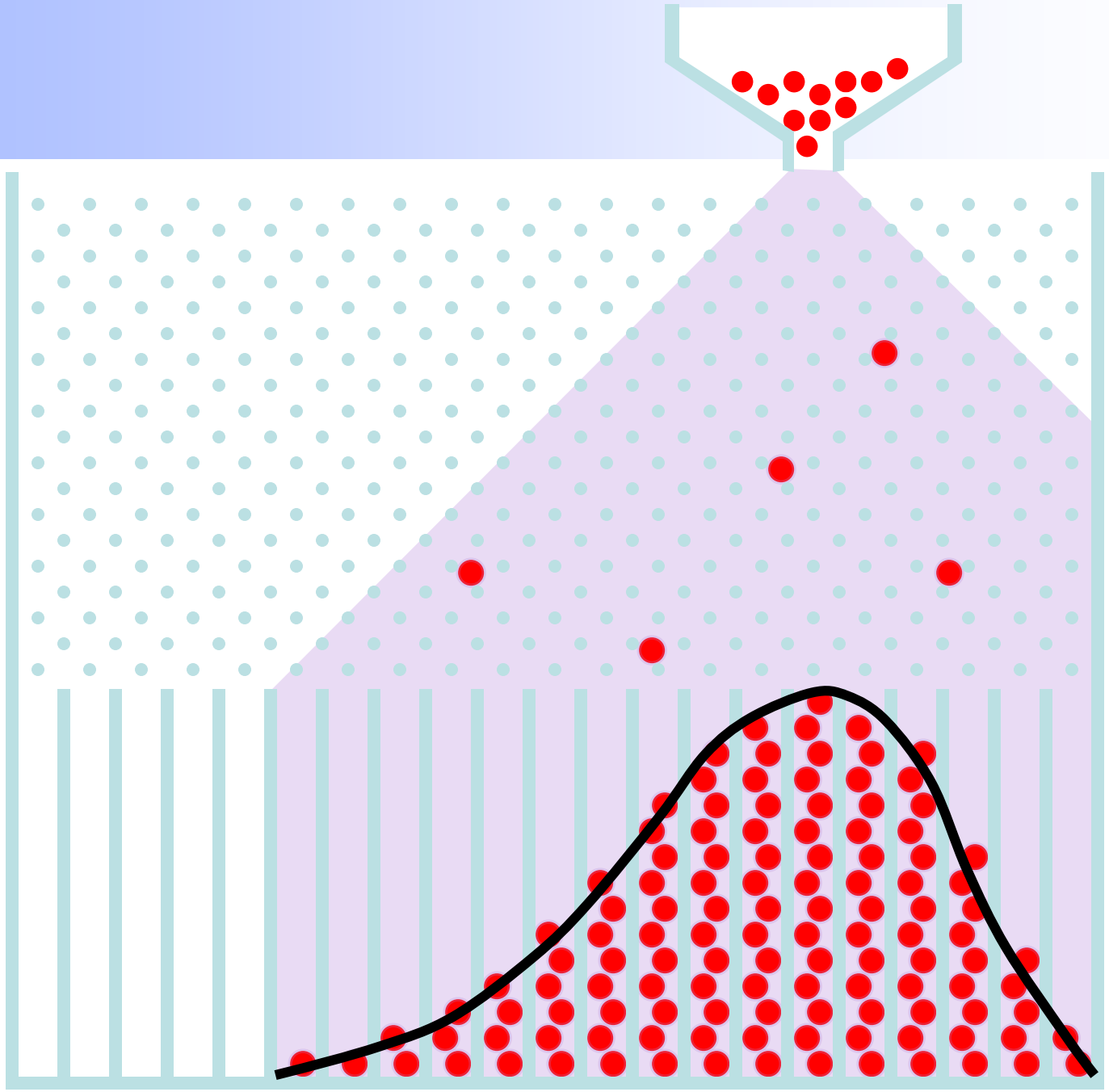


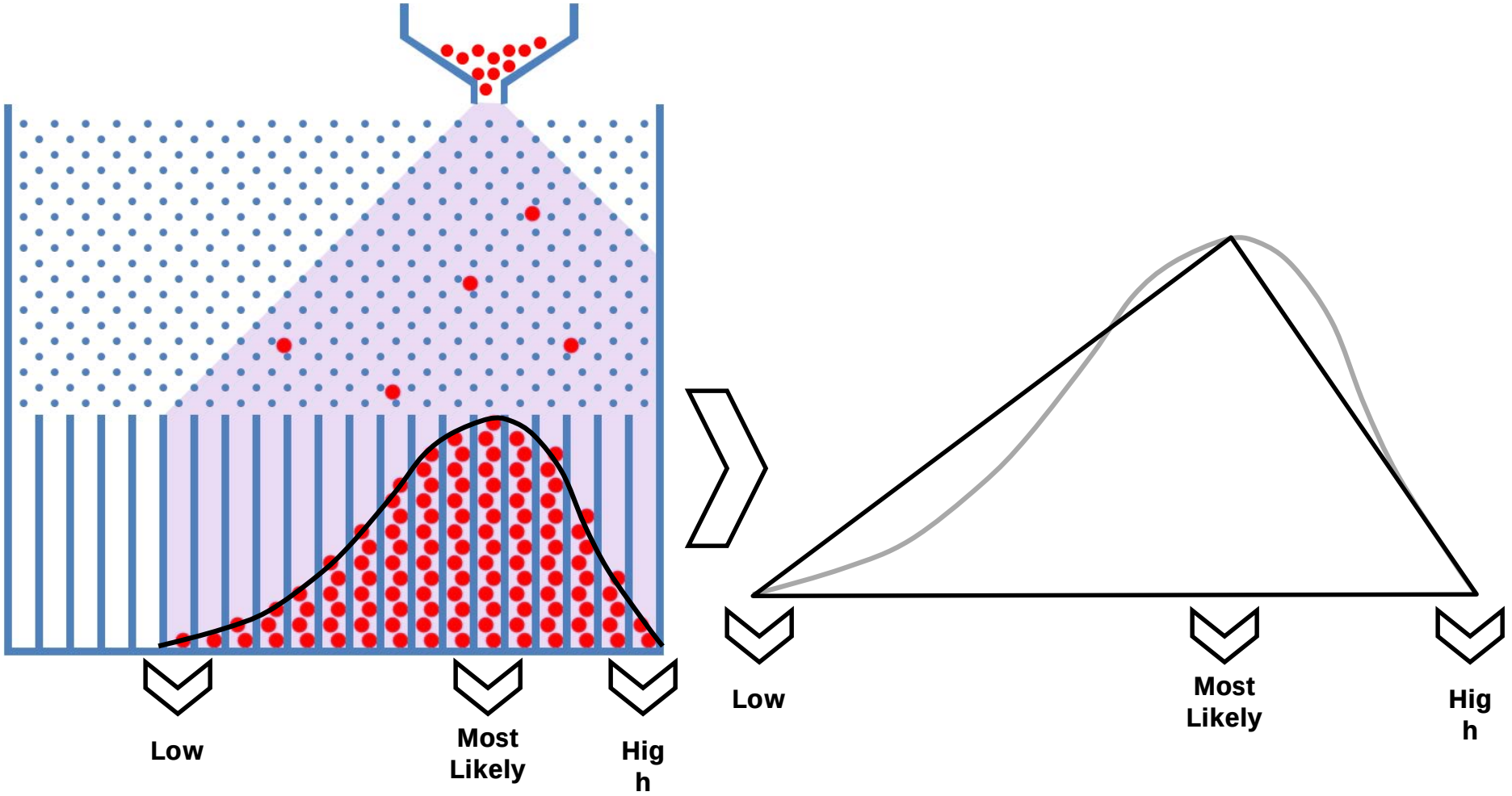


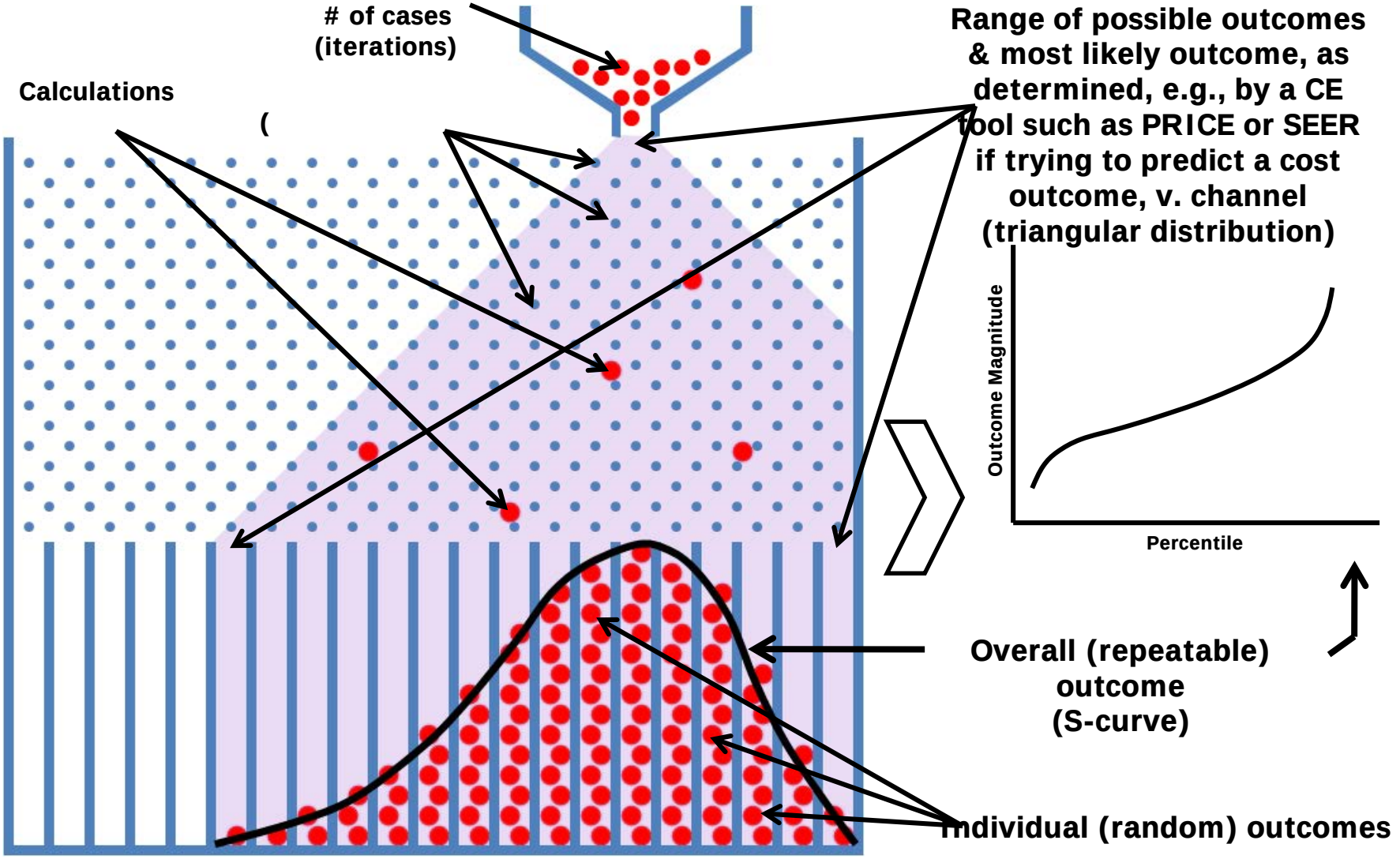





21
11
1
Channel number
Cumulative number of balls
1 3 5 8 12 17 25 36 49 63 78 92 105116124129133136138140141
Cumulative number of balls
1 3 5 8 12 17 25 36 49 63 78 92 105116124129133136138140141
OR
Cumulative number of channels
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Ball range, converted to 0-100 basis (%)
0
50
100
Random result guaranteed to be > this value's y-axis counterpart (channel 1)
Even chance of random result being < or > this value's y-axis counterpart (channel 11)
Random result guaranteed to be < this value's y-axis counterpart (channel 21)




Low
Most Likely
Hig h
Low
Most Likely
Hig h


# of cases
(iterations)
Calculations
(
Range of possible outcomes & most likely outcome, as determined, e.g., by a CE tool such as PRICE or SEER if trying to predict a cost outcome, v. channel (triangular distribution)
Outcome Magnitude
Percentile
Overall (repeatable) outcome (S-curve)
Individual (random) outcomes

ISS QRA Process

Data Sources

ISS Risk Management Application

Cost Risk by
Level 1 >50%
Level 2 50/50
Level 3 <50%

Pull Reports via Excel export

Run Automation Macros

Model Specific Inputs

Assign Probability Distribution

L1 (.17,.27,.47)
L2 (.0, .05, .15)
L3 (0, .03, .1)

Assign Cost Uncertainty Distribution

Design (.33, 1.00, 2.71)
Process (.06, 1.0, 2.65)
PM (.51, .95, 3.30)

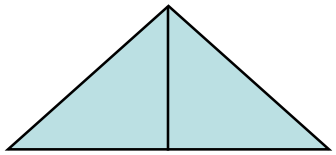
Model Outputs

Cost Model
@Risk (Monte Carlo Simulation)

Risk Triangle
Auto Convergence
QRA Estimate = (Probability Distribution) X (Uncertainty Distribution) X (Threat $)

FY15,FY16,FY17, FY18,FY19,FY20,FY21

Uncertainty Distribution (Triangle)



Low | Most Likely | Hi

QRA purpose

- **ISS Program viewpoint**
  - At the macro level, the QRA allows the ISS Program Management to forecast and manage both near term and far term program budget reserve requirements and allocations
  - QRA forecasts have been integral to the development of recommendations to the Program Manager relative to program cost control and informed risk management and effective reserves management approaches
  - The QRA enables Program Management to measure the expected impact the program threats will have on program reserves
  - Program also uses QRA to aid proactive planning in order to respond to potential Agency funding changes

- **ISS Program Planning & Control (PP&C) Viewpoint**
  - QRA tool is currently used in several Assessments team reports

- **The QRA projection of reserves impacts is also an integral part of the Program Risk Advisory Board (PRAB) quarterly activities**
  - The QRA data also supports the ISS Resources team cost containment analyses

QRA Output

- **What ISS reports use QRA?**
  - To support the PRAB as well as EWS and IMPR, ISS Program Threats reports from Integrated Risk Management Application (IRMA) are used

- **What method does ACES use to do the QRA?**
  - ACES uses a combination of Palisades Corp.@ Risk software package and modeling capabilities of Microsoft Excel
  - @Risk uses a certain number of simulations to combine all uncertainties identified and possible value and likelihood of occurrences in the model to determine a possible cost impact
  - Microsoft Excel is used for developing simulation models to allow risk analysis capabilities through probability distribution using functions that accept varied distribution types for cell value

Levels and Uncertainties

- **As input for the QRA model, ACES uses a combination of probability and K-factor distributions, applying triangular distributions**
  - Threats are categorized into “Probability Levels” based on likelihood of their occurrence and are expressed as a triangular distribution
    1. Level 1 will most likely occur (0.15, 0.27, .47)
    2. Level 2 are not likely to occur (0, 0.05, 0.15)
    3. Level 3 are not likely to occur (0, 0.03, 0.1)

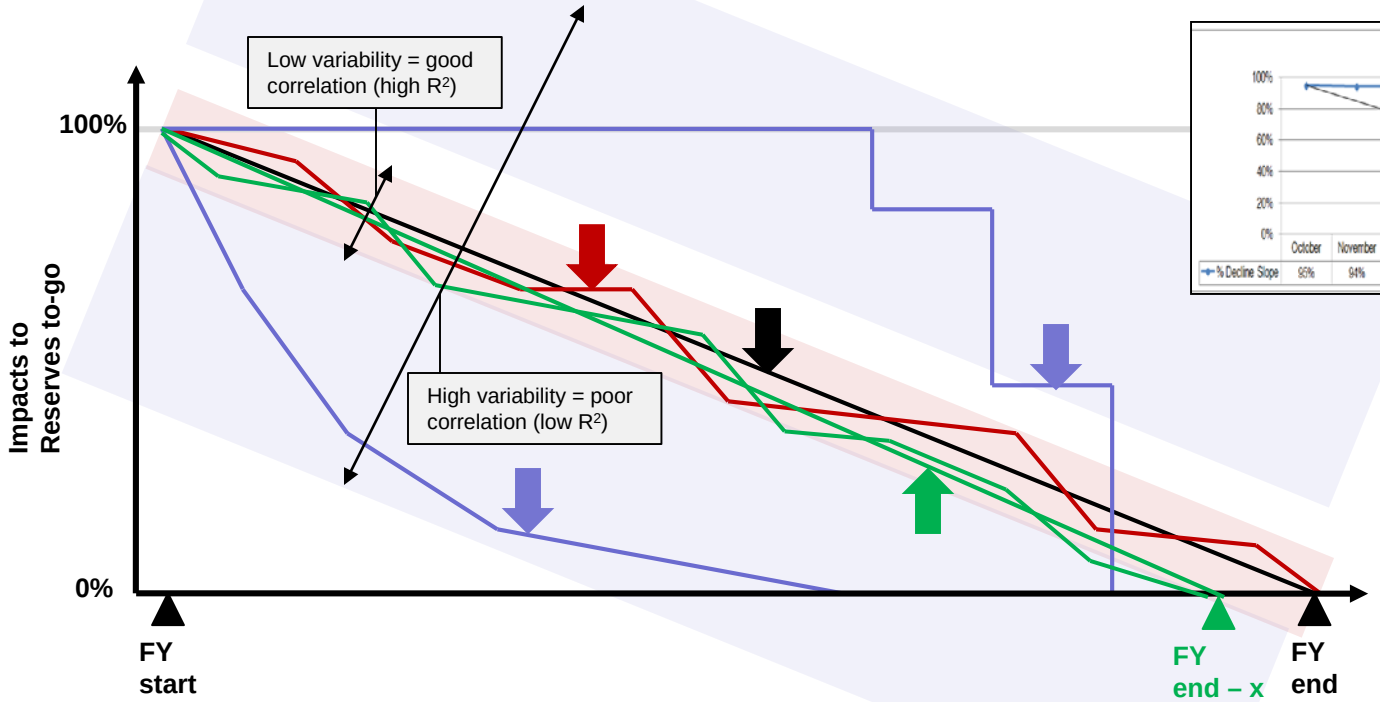
  - Threats are also categorized into “K factors” based on the type of task and the likely cost of occurrence expressed as a triangular distribution
    1. Design & Development (.33, 1.00, 2.71) – development, design analysis, testing
    2. Process (0.06, 1.00, 2.65) – operation and maintenance of existing systems
    3. Management (0.51, .95, 3.3) – rate increases, contract negotiations, major mods

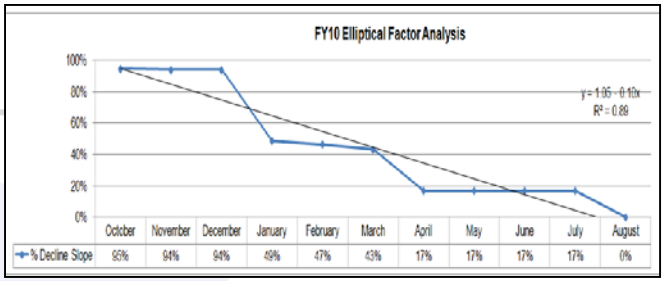
*** QRA estimate = (Probability Distribution) X (K factor Distribution) X (Threat $)**

To-Go Factor

- Since factor is not part of QRA's probabilistic role, expected behavior is for to-go actuals to vary slightly about a descending line connecting 100% FY start and 0% at EOY

- Most years were as expected (only 2 outliers for early/late starts; 2 for step-function realization of threats)





Key:

- = Ideal behavior (like-$, random risks); slope = -1/# mos., # mos. = 12
- = Directed, nonrandom behavior; violates premise behind monte carlo
- = Realistic ideal behavior (unlike $, random risks); slope as in ideal case
- = Realistic ideal behavior, modified to account for ability to cost $ by EOY; slope as before, with # mos. < 12

Fall off

- Fact that reserve impact history seems to follow a well-correlated linear path supports randomness assumption central to use of Monte Carlo techniques in ISS QRA

- Fact that EOY total RIT is reached by the end of August in every FY studied supports use of to-go factor

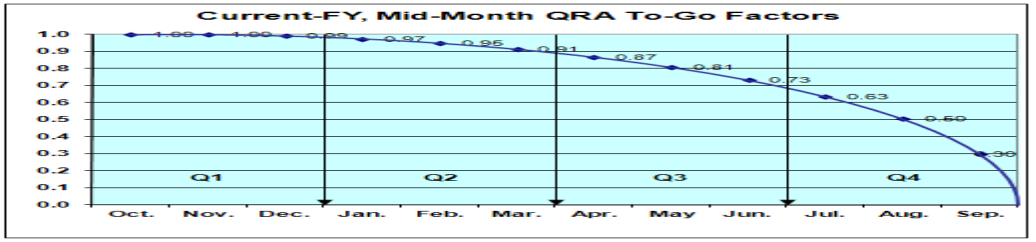
- Recommend implementation of modified to-go formulation as tabulated above and illustrated below

	Month (Current FY)	End-of-Month QRA To-Go Factor	Mid-Month QRA To-Go Factor
1	Oct.	1.00	1.00
2	Nov.	1.00	1.00
3	Dec.	0.98	0.99
4	Jan.	0.96	0.97
5	Feb.	0.93	0.95
6	Mar.	0.89	0.91
7	Apr.	0.84	0.87
8	May	0.77	0.81
9	Jun.	0.69	0.73
10	Jul.	0.57	0.63
11	Aug.	0.42	0.50
12	Sep.	0.00	0.30

Mid-month QRA To-Go Factor

$$F = [1 - (m - 1.5)^2/121]^{1/2}$$

Where F is the to-go factor & m is the # of months into the current FY.



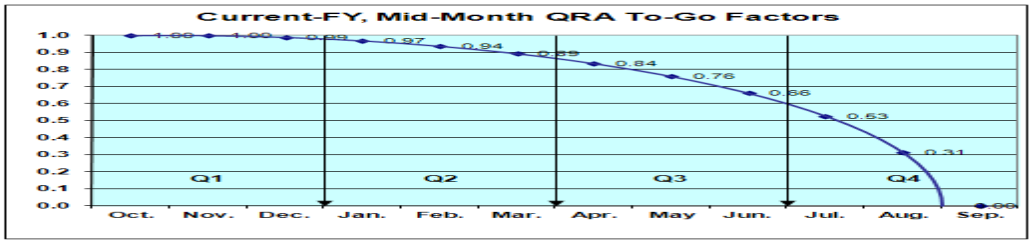
Basis: Upper-right quadrant of ellipse centered at (1,0), extending from (-10,0) to (12,0) & from (0,-1) to (0,1), where x=1 & x=12 represent end-of-Oct. & -Sep. within current FY.

	Month (Current FY)	End-of-Month QRA To-Go Factor	Mid-Month QRA To-Go Factor
1	Oct.	1.00	1.00
2	Nov.	0.99	1.00
3	Dec.	0.98	0.99
4	Jan.	0.95	0.97
5	Feb.	0.92	0.94
6	Mar.	0.87	0.89
7	Apr.	0.80	0.84
8	May	0.71	0.76
9	Jun.	0.60	0.66
10	Jul.	0.44	0.53
11	Aug.	0.00	0.31
12	Sep.	0.00	0.00

Mid-month QRA To-Go Factor

$$F = [1 - (m - 1.5)^2/100]^{1/2}$$

Where F is the to-go factor & m is the # of months into the current FY.



Basis: Upper-right quadrant of ellipse centered at (1,0), extending from (-10,0) to (12,0) & from (0,-1) to (0,1), where x=1 & x=12 represent end-of-Oct. & -Sep. within current FY.

QRA Annual Shifts

	Prior FY04-FY08 QRA (%)			Improved FY15 QRA (%)		
Level	Low	**Expected**	High	Low	**Expected**	High
1	58	**79**	100	15	**27**	47
2	0	**6**	12	0	**5**	15
3	0	**2**	4	0	**3**	1

ANY QUESTIONS?

Back Up

K factors

Uncertainty Factors: The Uncertainty Factors are defined as: Design & Development, Process, Management

Historical spacecraft design, development and operations cost data were collected from 1964 to 1993 in 347 programs and used to determine the uncertainty factors:

Shuttle: 19 Flights
Solar System Exploration: 51
Manned (I.e. Apollo, Skylab and Spacelab): 29
Planetary Landers: 41
Normal (a catch-all for all others and the experiment packages onboard): 207

K Factor definitions

- **Design & Development:**
  - Any threat associated with a WBS whose primary purpose is the performance of systems engineering tasks which produce an original design or redesign an existing system. These tasks would include requirements development (derivation, allocation, integration, etc.), design analysis (thermal, stress, FMEA, etc.), testing (developmental, qualification, integration, etc.) and other systems engineering task normally associated with the design of the new equipment.
- **Process:**
  - Any threat associated with a WBS whose primary purpose is the accomplishment of a systems operations process. Processes that would fit into this category are those associated with the operation and maintenance of existing systems. These processes range from hardware and software ground processing, to equipment maintenance record keeping. The key characteristic of these activities is the work associated with these WBS's as a function of system operations loading.
- **Management:**
  - Any threat associated with the performance of program management activities. Program management activities deal primarily with the administrative aspects of the program. Activities that would belong to this category would include contract negotiation outcomes (rates) and major modification approvals

References

- Case Study: Application of Quantitative Risk Analysis (QRA) to Risk Management in the International Space Station (ISS) Program: Michael Jansen & Richard Fox
- Decision Making and Quantitative Risk Analysis using the Decision Tool Suite: *Palisade Software Seminars*
- ISS QRA Validation Summary
- NASA Space Flight Program and Project Management Handbook (NPR 7120.5E)
- Monte Carlo Simulations: Eric Druker *Booz Allen Hamilton*