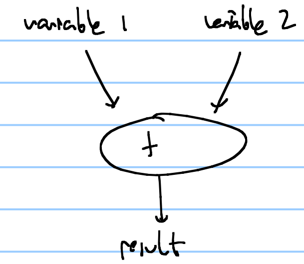
- Uncertainty quantification

especially big during the development phase

One way already covered. Ceteris Paribus → sensitivity analysis → purpose evaluate how KPI (key performance indicator) varies with input



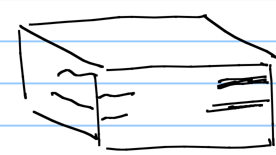
does not allow to evaluate ALL possible outcomes

Probabilistic reserve estimation

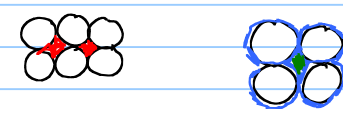
$$N = \frac{V_R \cdot \Phi \, S_o \, N_{TG}}{B_o}$$

Net to gross

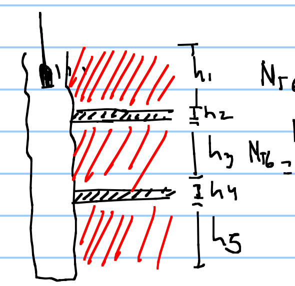
OOIP


Box-shaped reservoir

There are variations on all variables in that formula



A probability distribution is typically used for variables that are uncertain

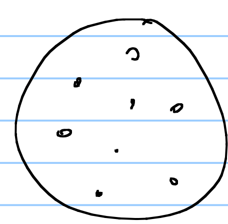


$$N_{TG} = \frac{h_1 + h_3 + h_5}{H}$$

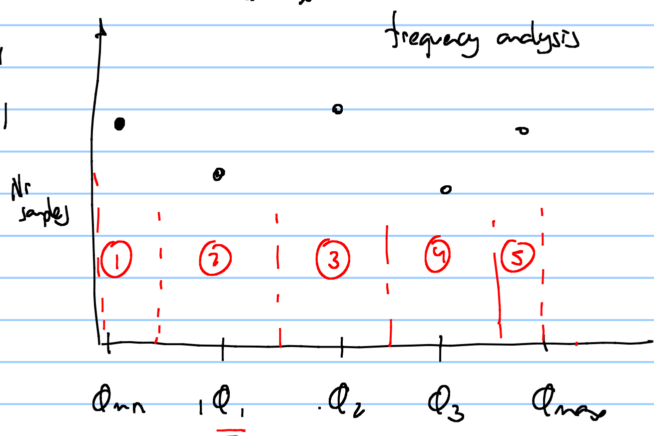
An example Φ 2287 core samples taken from exploration wells

Sample	Observed
1	Φ_1
2	Φ_2
3	Φ_3
4	Φ_4
⋮	⋮

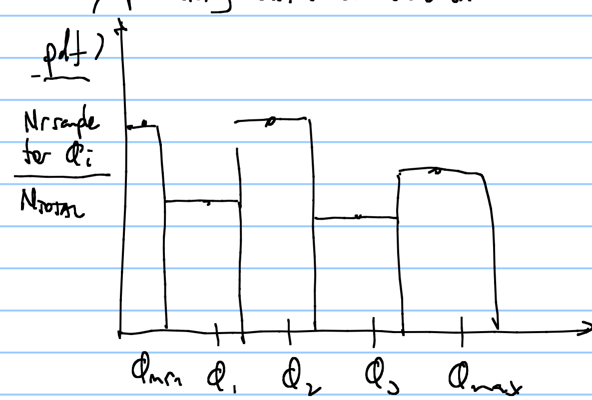
Φ_{min}
Φ_1
Φ_2
Φ_3
Φ_{max}



frequency analysis

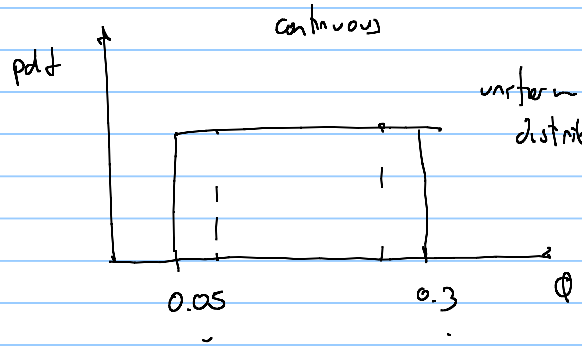


discrete probability distribution function



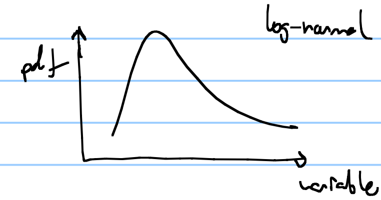
if I haven't made any measurements of porosity, I can assume a distribution

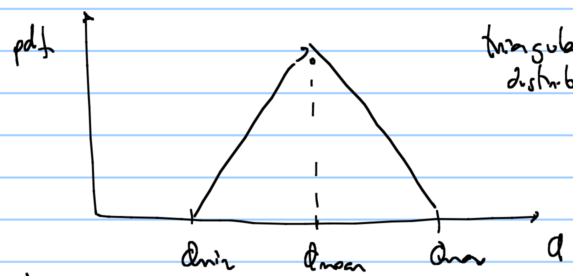
continuous

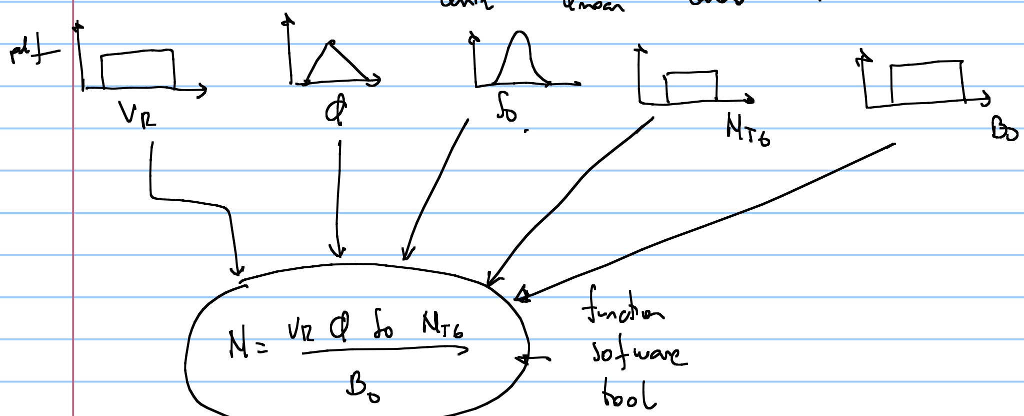


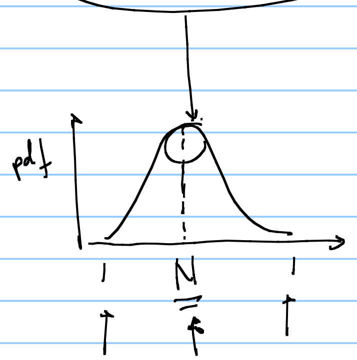
$\phi_{min} = 0.05$

$\phi_{max} = 0.30$









the output distribution is affected by
- the distribution of input
- the type of function

Needed for:
Business identification phase
PDO

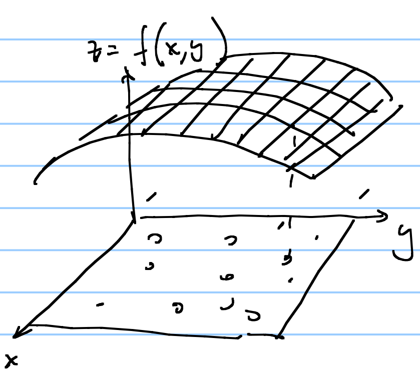
How to calculate the pdf of the output?

Sampling methods

Random sampling

$x_1 \;\; y_1 \rightarrow z_{11}$

$x_1 \;\; y_2 \rightarrow z_{12}$



this is called Monte-Carlo method

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THE MONTE CARLO METHOD

NICHOLAS METROPOLIS AND S. ULAM
Los Alamos Laboratory

We shall present here the motivation and a general description of a method dealing with a class of problems in mathematical physics. The method is, essentially, a statistical approach to the study of differential equations, or more generally, of integro-differential equations that occur in various branches of the natural sciences.

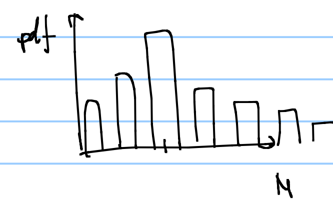
to calculate pdf of output

repeat for N times

- assume a random number for input (for each variable)
- run simulation / calculate output
- Register / store output

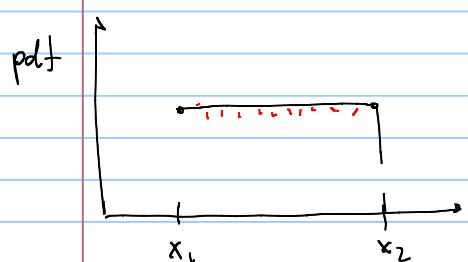
Apply a frequency analysis on output

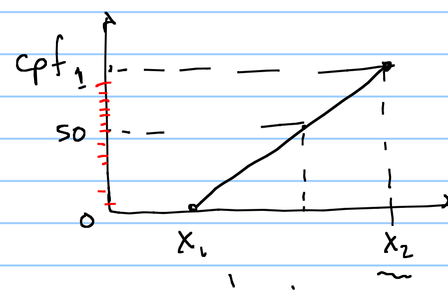
obtain pdf



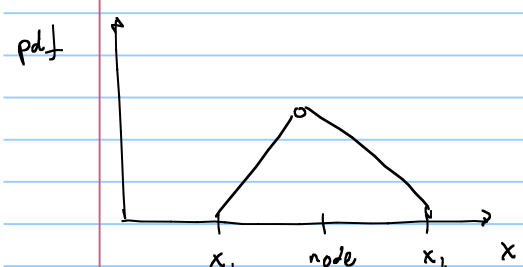
N should be chosen such as the resulting pdf doesn't change significantly

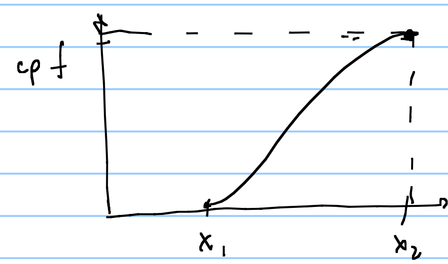
the random sampling is typically done on cpf (cumulative probability function)





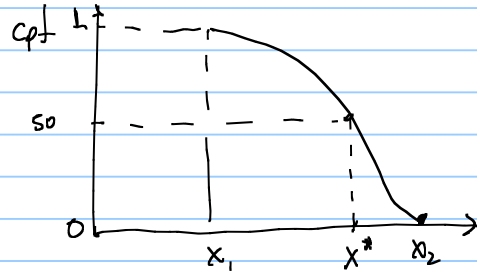
$$X = X_{min} + RAN()(X_{max} - X_{min})$$



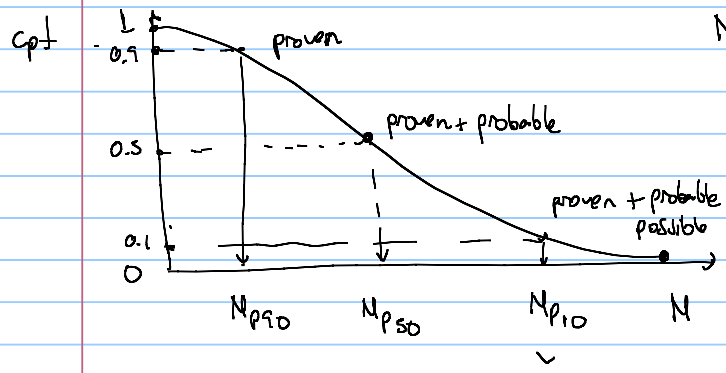



```
'****Triangular distribution****
'Value of the variable X , randomly generated

'a = minimum value
'b = maximum value
'c = mode

Function X_triang(a, b, c)
U = Rnd()
Fc = (c - a) / (b - a)
Application.Volatile (True)
If U < Fc Then
X_triang = a + (U * (b - a) * (c - a)) ^ 0.5
Else
X_triang = b - ((1 - U) * (b - a) * (b - c)) ^ 0.5
End If

End Function
```

cpf can also be plotted



for reserves we used the "reversed" cpf



N_{P90} there is 90% probability that N is equal or higher than P90

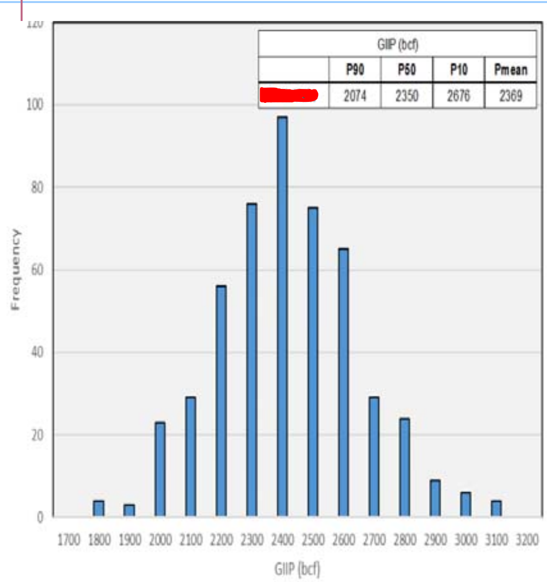
N_{P50} there is 50% probability that N is equal or higher than P50

N_{P10} there is 10% probability that N is equal or higher that P10

Some companies / countries use different %

Table 5.2-1: Hebron Ben Nevis (Pool 1) In-Place Volumes Range

Hebron Ben Nevis Oil	Upside Volumes		Best Estimate Volumes		Downside Volumes	
	MBO	Mm^3	MBO	Mm^3	MBO	Mm^3
D-94 Fault Block	1601	255	1328	211	1077	171
I-13 Fault Block	252	40	187	30	141	22
Total Hebron Ben Nevis	1870	297	1515	241	1204	191



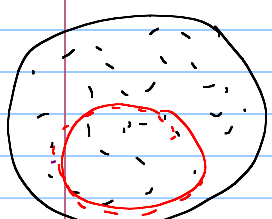
the applicability of Monte Carlo depends on the running time of "function" "simulator"

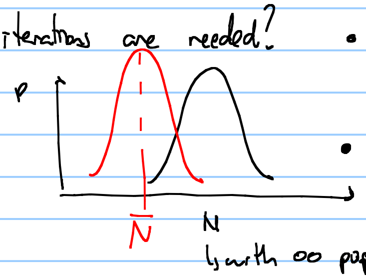
How many iterations are needed?

- Procedure 1 trial and error increase "N" until results don't change
- $n_{it} = \left(\frac{3 \cdot S_x}{Error} \right)^2$ central limit theorem

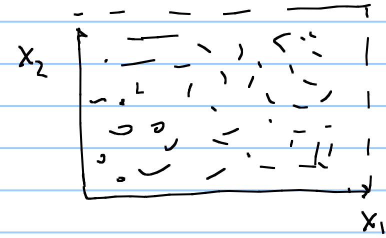
3-1 standard deviation

3-7% $\bar{N}$ ~ average of simulation point



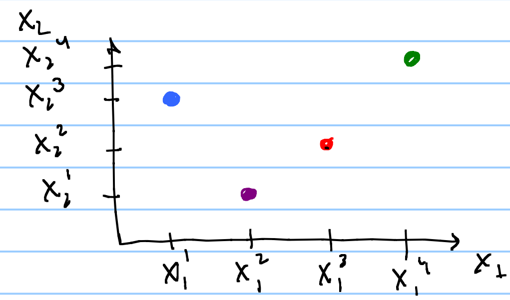


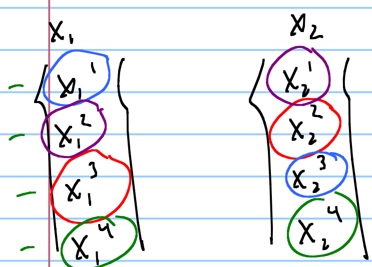
there are other sampling method



Latin hypercube

create N points for each variable. N is the number of simulations





Simulation 1

$x_1^3 \quad x_2^2 \rightarrow$

Simulation 2

Simulation 3

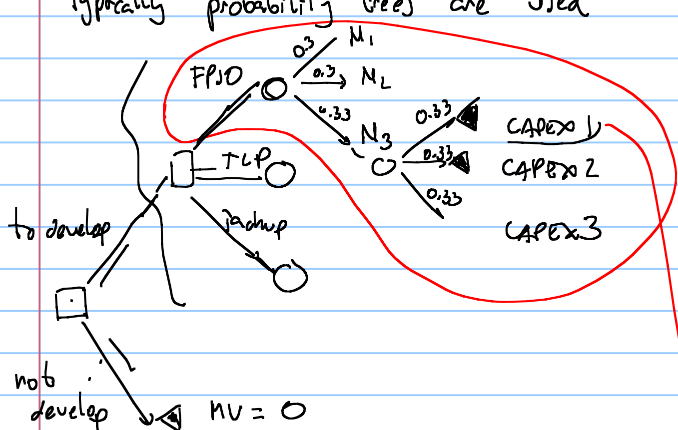
Simulation 4

What happens when Monte Carlo takes a very long time? → impractical

When I have non-continuous variables?

FPSO
TLP
Jackup

typically probability trees are used



□ decision nodes

○ chance nodes

◀ terminal node

chance nodes come with a probability!

layer 1	layer 2	layer 3	layer 4
develop decision	offshore structure	reserve size	cost

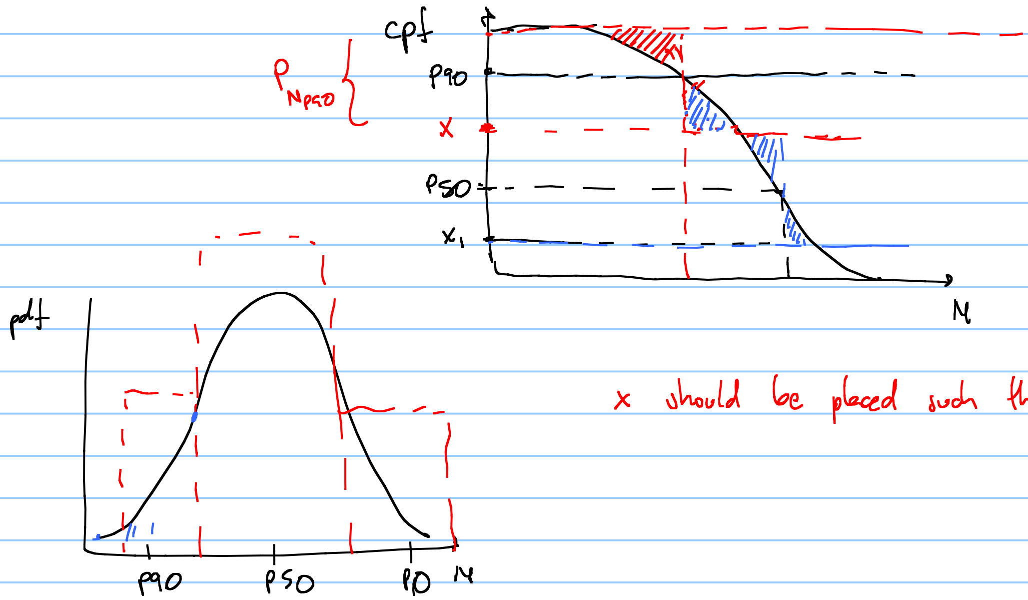
FPSO, N_3, CAPEX 1

EMV expected monetary value (NPV)

Probability of option

$P_{N_3} \cdot P_{CAPEX_1} = 0.33 \cdot 0.33$

If I wish to use $N_1 = P10$ what are probabilities?
$N_2 = P50$
$N_3 = P90$



x should be placed such that [red hatched area] = [blue hatched area]

option: to calculate the EMV of a branch

$$EMV_{branch} = \sum_{i=1}^{N} P_i \, EMV_i \quad \text{of all options on that branch}$$