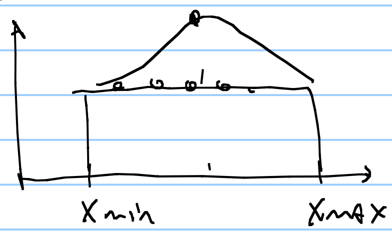
- Reference group: Wilfred, Erca
  Kjørslevik, Erik Kristoffer Carlsen
  Mkinga, Oras Joseph

- Uncertainty quantification and management.

for each variable in my field development process it is necessary to determine a probability distribution
ϕ
P_{Ri}



Probabilistic estimation of total recoverable reserves

		TRR	
oil	G		G_{pu} ultimate cumulative gas production
gas	N		N_{pu} ultimate cumulative oil production

recovery factor

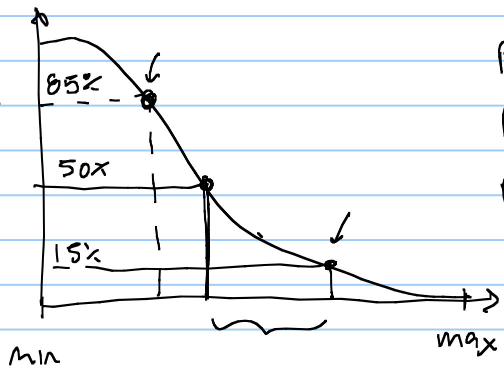
$$RF,\ F_{RU} = \frac{N_{pu}}{N} \begin{cases} 20\% \\ 50\% \end{cases}$$

$$= \frac{G_{pu}}{G} \begin{cases} 30\% \\ 70\text{-}80\% \end{cases}$$

$$N_{pu} = \int_0^{t_{end}} q_o(t)\,dt$$

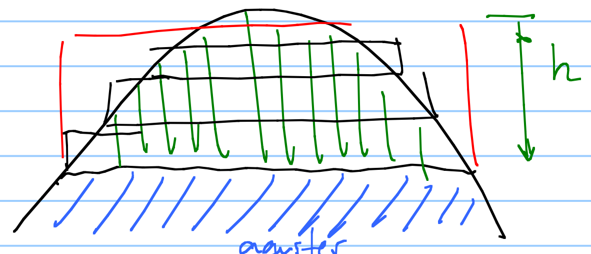
__Desired output__

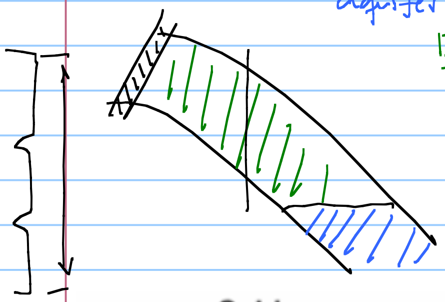
cumulative distribution probability TRR

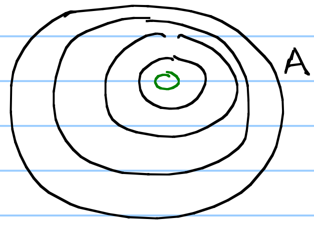


P_{85} = proven
P_{50} = proven + probable
$P_{15\%}$ = proven + probable + possibe

oil reservoir







~ view from top

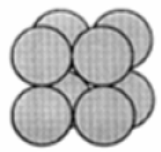
$V_{PR} = h \cdot A$

$V_{PR} = \sum_{i=1}^{N_{layers}} h_i \cdot A_i$

Rock bulk volume

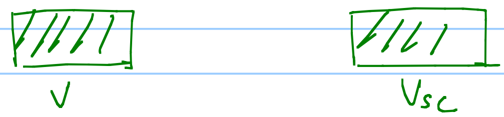
$\phi = \frac{\text{Pore volume}}{\text{total volume}}$

$$TRR = N_{pu} = \underbrace{\frac{\overbrace{V_{PR} \cdot \phi}^{\text{pore volume}} \cdot \overbrace{(1-S_w)}^{\text{adimensional}} \overbrace{\left(\frac{N}{G}\right)}^{\text{adimensional}}}{B_o}}_{N} \cdot Fr_u \qquad Sm^3,\ stb$$



Porosity = $\frac{\text{Pore volume}}{\text{Bulk volume}}$ =

p, T → T_{sc} (15.56°C), p_{sc} (101325 bara)

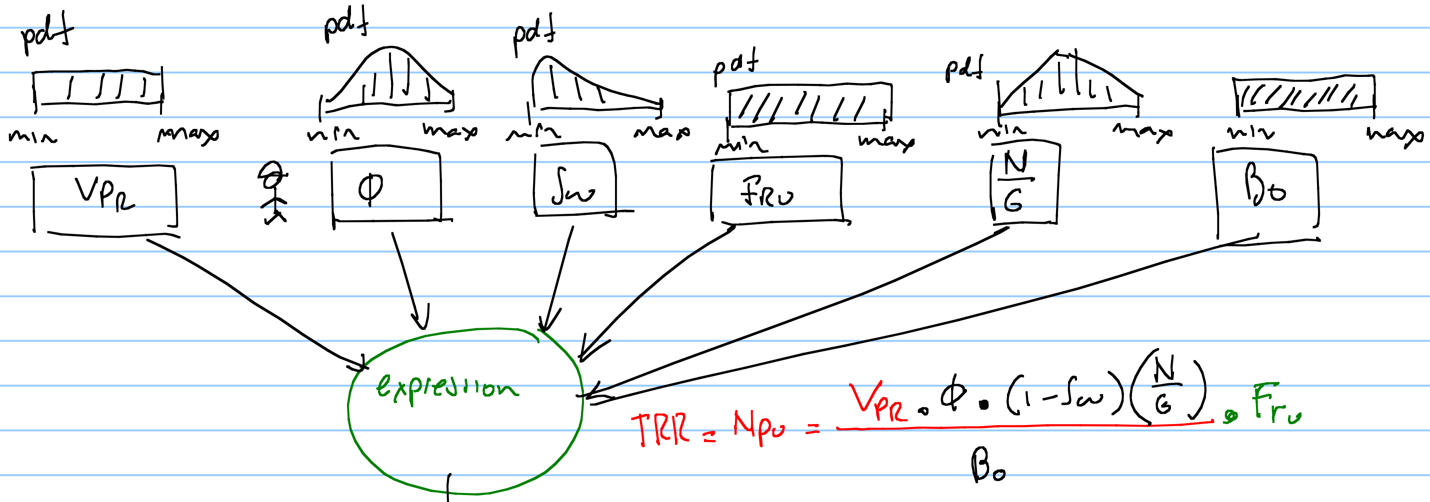


$B_o = \frac{V_o(p,T)}{V_{sc}}$

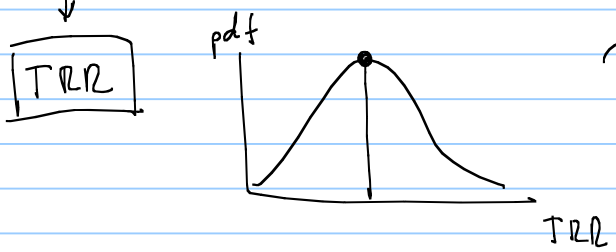
Uncertainties in IOIP Estimation

Factor	Typical source of estimate	Approximate range of expected accuracy (%)
Area	drill holes	± 10–20
	geophysical data	± 10–20
	regional geology	± 50–80
	cores	± 5–10
Pay thickness	logs	± 10–20
	drilling time records and samples	± 20–40
	regional geology	± 40–60
Porosity	cores	± 5–10
	logs	± 10–20
	production data	± 10–20
	drill cuttings	± 20–40
	correlations	± 30–50
Interstitial water saturation	capillary pressure data	± 5–15
	oil base cores	± 5–15
	saturation logs	± 10–25
	routine cores with adjustments	± 25–50
	correlations	± 25–60
Formation volume factor	pressure volume temperature analysis of fluid samples	± 5–10
	correlation	± 10–30

- **Recovery factor, F_R depends on:**
  - Permeability and Permeability distribution
  - Relative permeability characteristics
  - Drive mechanism
  - Pressure support, displacement and sweep efficiency
  - Reservoir architecture-continuity, shape, layering, fault blocks
  - Reservoir anisotropy
  - Reservoir fluid properties
  - Well placement. Number of wells
  - Artificial lift
  - Minimum economical field rate

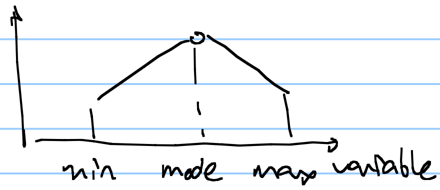


$$TRR = N_{pu} = \frac{V_{PR} \cdot \phi \cdot (1-S_w)\left(\frac{N}{G}\right)}{B_o} \cdot F_{Ru}$$



?

for the input variables engineers usally use a uniform (rectangle) distribution or a triangle distribution



- to obtain the probability distribution of TRR engineers often use the Monte-Carlo method

↳ Stanisław Ulam, Los Alamos 1940 } Monte-Carlo
Von-Neuman

1. • Define a domain of possible values for each input variable { propose, find a probability distribution

2. • Generate a random input for each variable using its pdf

3. • Perform a deterministic calculation using { equation, simulator, routine } depending on the model available
   Compute the value(s) of interest.

4. • Repeat step 2. for "many" time. for our case 8000 iterations

achieved required number of iterations

Aggregate all results TRR(s) and perform, compute its pdf, cdf

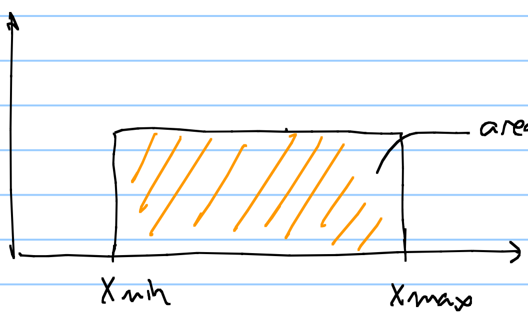
the applicability of Monte-Carlo method depends on how long it takes for step 3 to complete

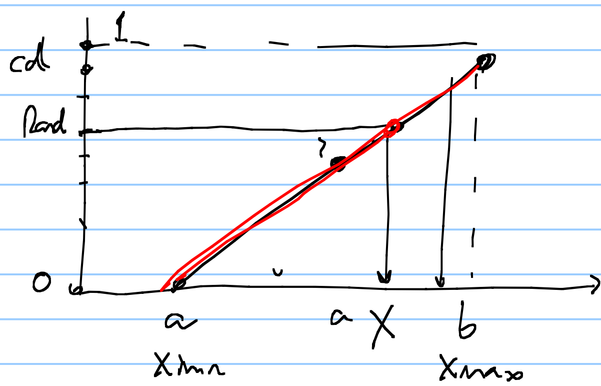
			Net to Gros	Oil Saturation	Formation Volume Factor	Ultimate Recovery Factor
	Rock volume	Porosity	N/G	So=(1-Sw)	Bo	Fr
	bbl	fraction	fraction	fraction	Res bbl/STB	fraction
Min	2000000000	0.18	0.3	0.8	1.35	0.42
Max	2500000000	0.3	0.5	0.9	1.6	0.65

~ pseudo Goliat

uniform distribution

$f(x) =$





$$\frac{1-0}{X_{max}-X_{min}} = \frac{Rand - 0}{(X) - X_{min}}$$

use excel Rand( ) Rnd( )

$$X = X_{min} + (X_{max} - X_{min})\,Rand$$

	Rock volume	Porosity	Net to Gros N/G	Oil Saturation So=(1-Sw)	Formation Volume Factor Bo	Ultimate Recovery Factor Fr
	bbl	fraction	fraction	fraction	Res bbl/STB	fraction
Min	2000000000	0.18	0.3	0.8	1.35	0.42
Max	2500000000	0.3	0.5	0.9	1.6	0.65

$V_{PR} = V_{PR\,min} + Rand_{V_{PR}} (V_{PR\,max} - V_{PR\,min})$

use formula $TRR = \dfrac{\phi \cdot V_{PR} (S_o)\, N/G}{B_o}$

	V_{PR} [bbl]	ϕ [-]	N/G [-]	S_o [-]	B_o [bbl/Stb]	F_{ro} [-]	TRR
1	0						0
2							
3							
⋮							
3000							

compute pdf cdf for this column

- Usually Monte Carlo is non practical for heavy models (Reservoir Simulator). thus another method calle Latin hypercube Sampling is used.