Fast algorithm for open pit mining: tackling uncertainty, design and capacity

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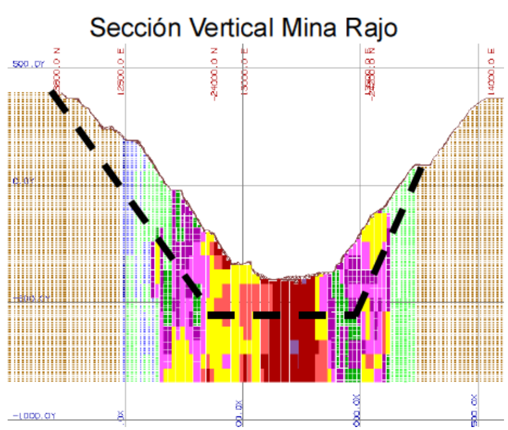
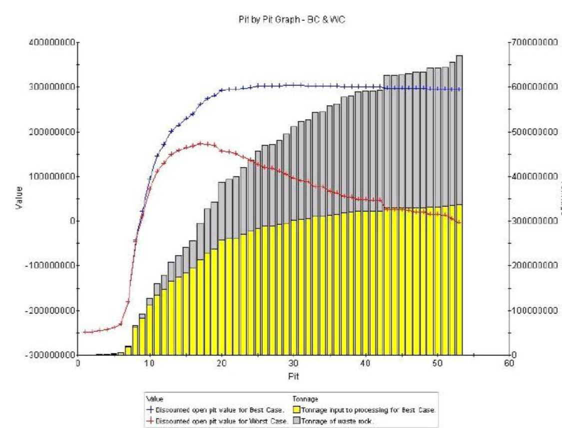
Summary

- Typical planning process is a serial methods of procedures, that use geostatistics data as input and need a post hoc design and capacity correction.
- We show an idea to joint planning, geostatistics and design, considering capacity.
- Simulated annealing and floating cones is just a excuse…

Classic planning process

Final Pit → Nested pits → Lifeti me → Phases → Equip, Design → Capex, Opex





Houston, we´ve had a problem here!

- We used a “mean” block model. What about uncertainty?
- Theoretical solution is not operative.

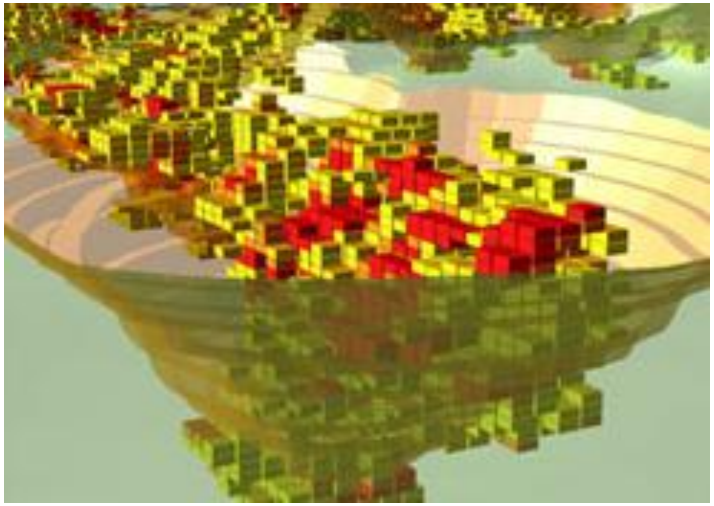
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	300	300	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10

Final Pit, as an example

- There exists efficients algorithms
- There are fast algorithms for scheduling that use Final Pits
- Divide and conquer

Lersch & Grossman

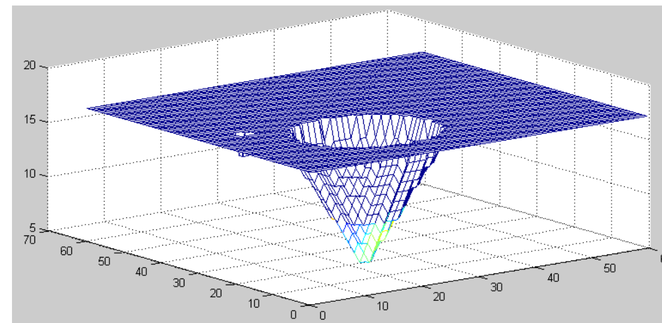
- **Translate** value maximization to a max flow in an oriented net.
- Slope is satisfied as a **precedence** relationship



Floating cones algorithm (Greedy)

- Accepting new cones while they add value

-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	300	300	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10



Remark (representation): in order to define the surface of final pit at left image, we need 2 points. Using Lerchs&Grossman we need 12.

Cones algorithms

Greedy

- Select a cone
- It is accepted:
  - Certainly if it adds value
  - Probably if it doesn't destroy too much value and iteration is not too advanced (cooling down).

Stop at fixed steps.

Simulated Annealing

- Select a cone
- It is accepted:
  - Certainly if it adds value
  - Probably if it doesn't destroy too much value and iteration is not too advanced (cooling down).

A "while" is running until system is frozen.

Why Simulated Annealing?

- There are success cases
- Planning process integrated
- Paralelized

Benchmark 1: small block model
Marvin Mine (62,220 blocks)

Marvin	Value	Block mined	Representation	Time (secs)
Pseudoflux	8.96E+11	6,568	621	2
Greedy	8.83E+11	6,454	128	5
S. Annealing	8.81E+11	6,447	507	22

Remark: Pseudoflux is faster and achieves optimum.

Benchmark 2: strong nugget effect Marvin + big Bernoulli noise

Marvin+Noise	Value	Block mined	Representation	Time (secs)
Pseudoflux	-	-	-	24hrs
Greedy	1.02E+12	20,602	339	10
S. Annealing	1.03E+12	17,956	638	20

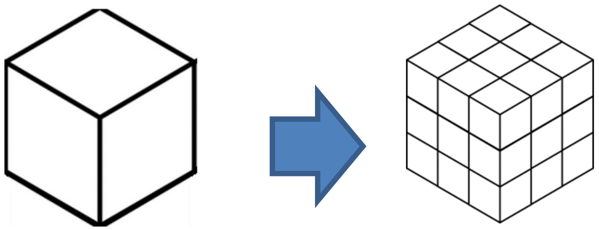
Remark: Pseudoflux does not achieve optimum after 24hrs.

$$\tilde{V}_i = V_i \pm \max_j |V_j|$$

Benchmark 3: big block model (Marvin refined to 1,297,770 blocks)

Big BM	Value	Block mined	Representation	Time (secs)
Pseudoflux	-	-	-	24hrs
Greedy	1.72E+13	698,828	1197	90
S. Annealing	1.53E+13	619,917	592	18

Remark: Simulated Annealing needs short time to achieve an almost optimum point.



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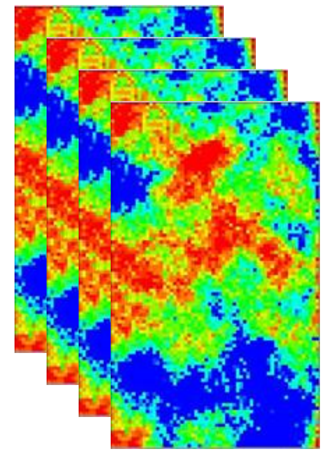
Conclusions for final pit

- Floating Cones with Simulated Annealing **could be more efficient** for big block models or strong nugget effect situations.
- Its **representation** is cheaper.
- It leads to try several **simulations** for block model.
- Cones is a cheap (and flexible) object to satisfy slope (and could fit mine **design**).

Remarks

- **Uncertainty**: try block model simulations inside the heuristics running, and accept new cones if its value distribution pass certain criteria. ***Joint planning and geostatistics.***
- **Design**: try truncated operative cones. It leads an operative final pit. ***Joint planning and desing.***



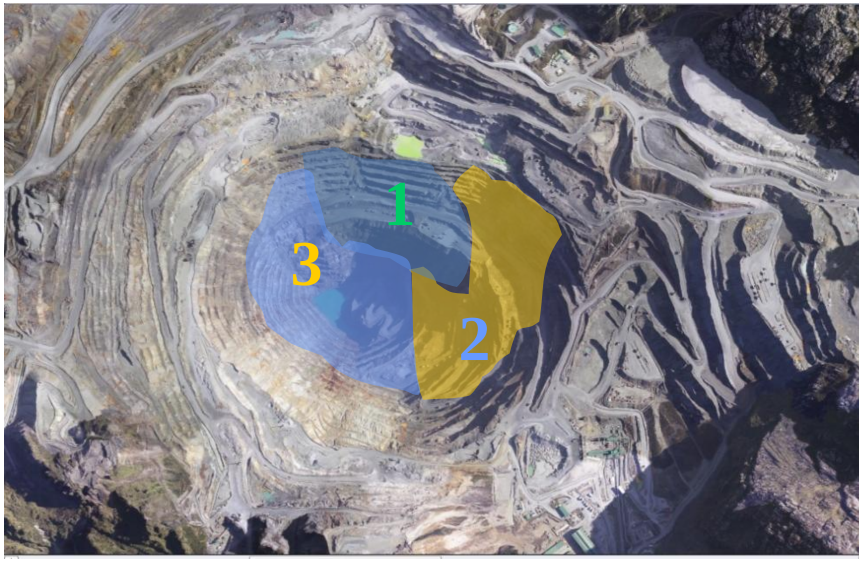
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	300	300	-10	-10	-10	-10	-10
-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10

Context

- This ppt is a part of a PhD thesis.
- Subject: Mine Planning under geological uncertainty.
- A priori approach:
  - Simulation and design embedded in optimization, turning bands
  - Simulated annealing to solver hard problems.
  - Strategy instead of rigid planning solution
- Final application: long term planning for open pit to underground transition

ALGORITHMS BASED ON AGGREGATION FOR THE OPEN-PIT BLOCK SCHEDULING PROBLEM

- **Scheduling**

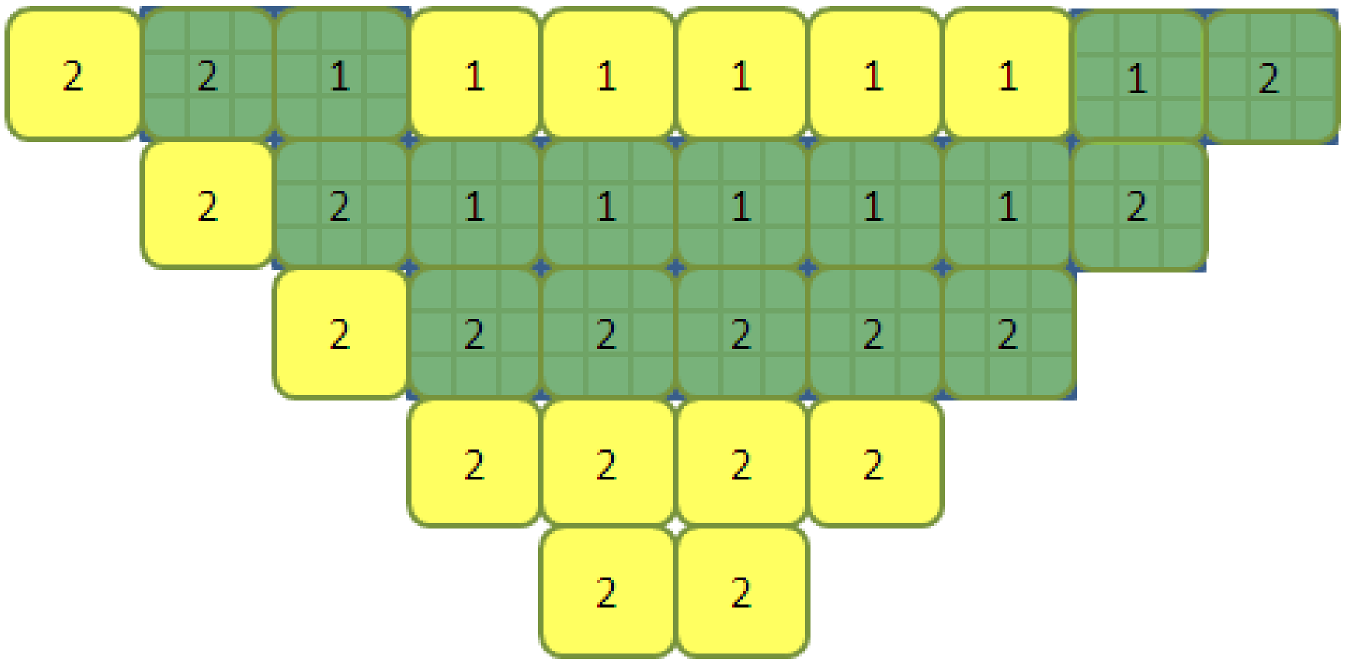


- Current techniques are based on Lerchs & Grossman algorithm (1965): It **does not consider** production and mining capacities, hence, it does not take time into account.

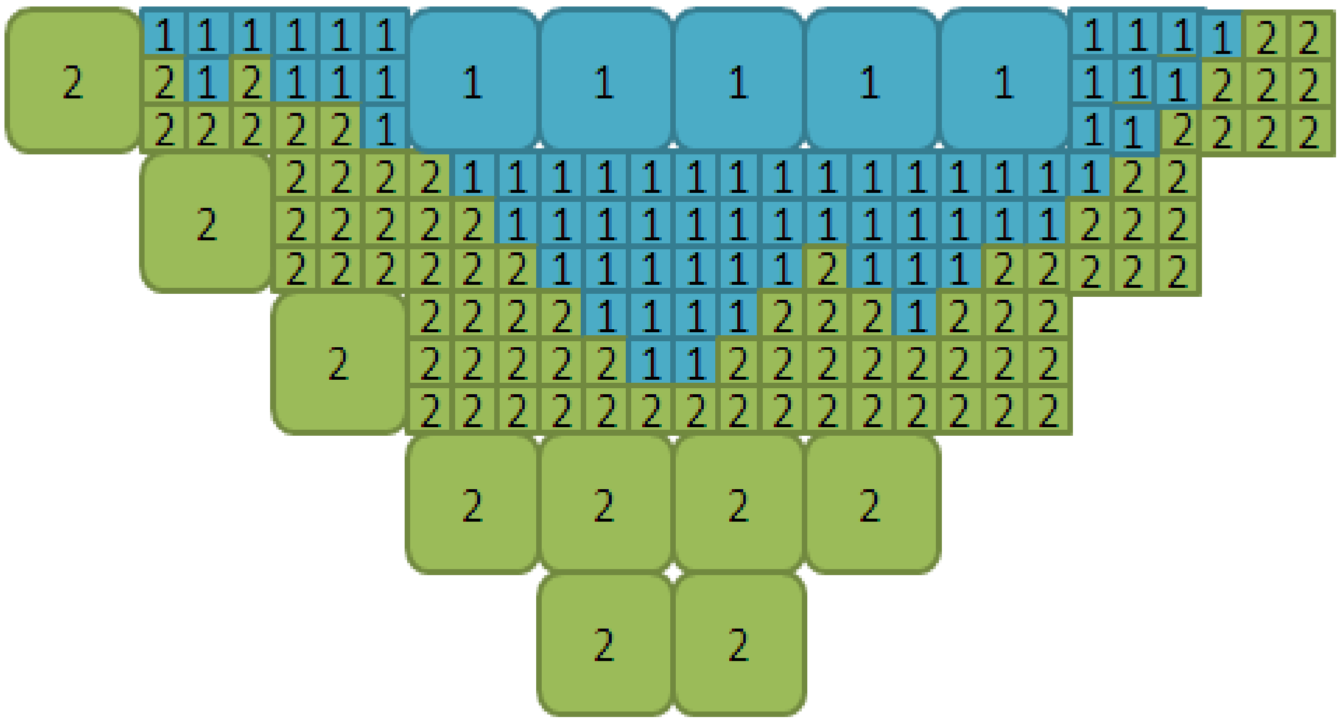
Main idea: Aggregation

- Use aggregation to reduce the complexity of the problem and heuristics to generate feasible (good) solutions:
  - Reducing number of periods
  - Relaxing constraints
  - Reblocking

Blocks in the *borders* are then refined and re-optimized



Final solution is reported at original block level



Case study : Marvin

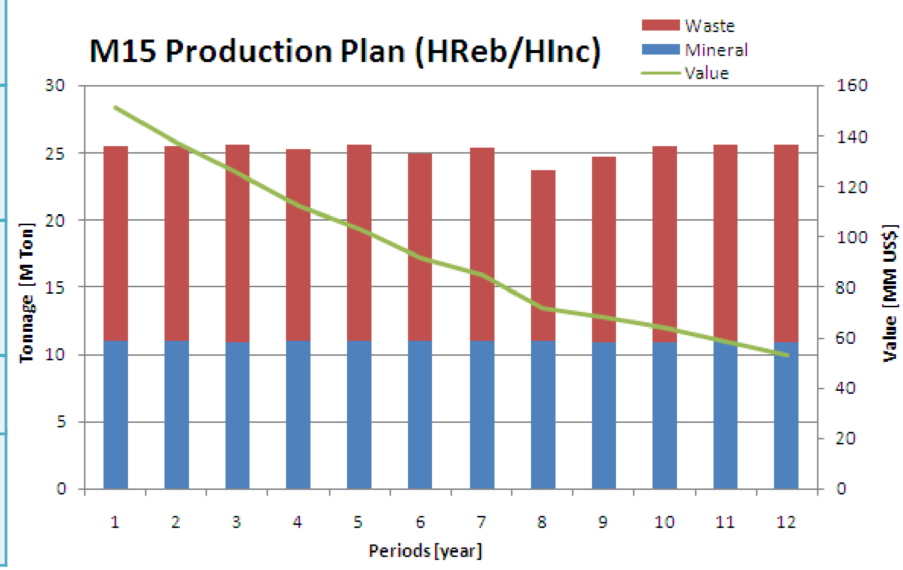
- Imaginary mine (but *well known*).
- About 12,500 blocks
- Discount rate: 10% per year
- 12 time periods
- Data blocks:
- Two capacity constraints:
  - Mining (transportation) is 70,000 [TPD]
  - Processing (plant) is 30,000 [TPD].
- Block predecessors:
  - Slope angle of 45 degrees

X	Y	Z	VALUE [US$]	TONNAGE	TON. PLANT
4075	7050	705	-10260	10260	0
4075	7050	675	-61587	61587	0
4075	7050	645	-61209	61209	0
4045	7170	705	-7776	7776	0
4045	7170	675	586059	67311	67311
4045	7170	645	1095213	72360	72360
4045	7170	615	1413201	72360	72360

Results

Mine	M15	M30
# Blocks	99,744	12,468
IP	OoM	OoM
LP	OoM -	1,246 7,235 [s]
HInc	- >10,800 [s]	1,134 312 [s]
HInc-STW	- >10,800 [s]	998 9,324 [s]
HReb/ IP	OoM	OoM
HReb/HInc	1,123 2,027 [s]	1,134 312 [s]

- Each cell reports the value (MMUS$) and time (sec) to reach the solution.
- IP: Original problem (unsolvable)
- LP (upper bound) is available only for the larger blocks, and gives gaps of about 9%.
- OoM = Out of Memory



Conclusions and further work

- Aggregation techniques allow to tackle instances that are "unsolvable" otherwise.
- Distribute computational effort (steps of algorithm) at multiple computers simultaneously (parallelization)
- Extend to the case where coefficients in capacity constraints may be negative (constraints on the average value of some attribute)
- Extend to the case where the model decides the destination of the block (cut ore grade not fixed)
- Stochastic case (geology, prices, operations).

Joining…

Joining: planning, geo-uncertainty, design, capacity

- Embebing uncertainty in planning with floating cones.
- Using turning bands to sampling (Stochatics Samping Aver.)
- Using operative cones to fix a design strategy
- Reblock to reduce difficulty in time.
- Parallelize sampling (turning bands), simulated annealing.

Acknowledgements

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Creating a rich environment to work in mine planning