Network Optimisation in the Access Design for Underground Mines

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Outline of talk

- Background
- Underground mine design access problem
- Mathematical model of a single mine decline
- The Shortest Network Problem
- Network of declines
- An industry case study, Prominent Hill mine

Growth in cities in China fuels Australia's minerals and resources boom

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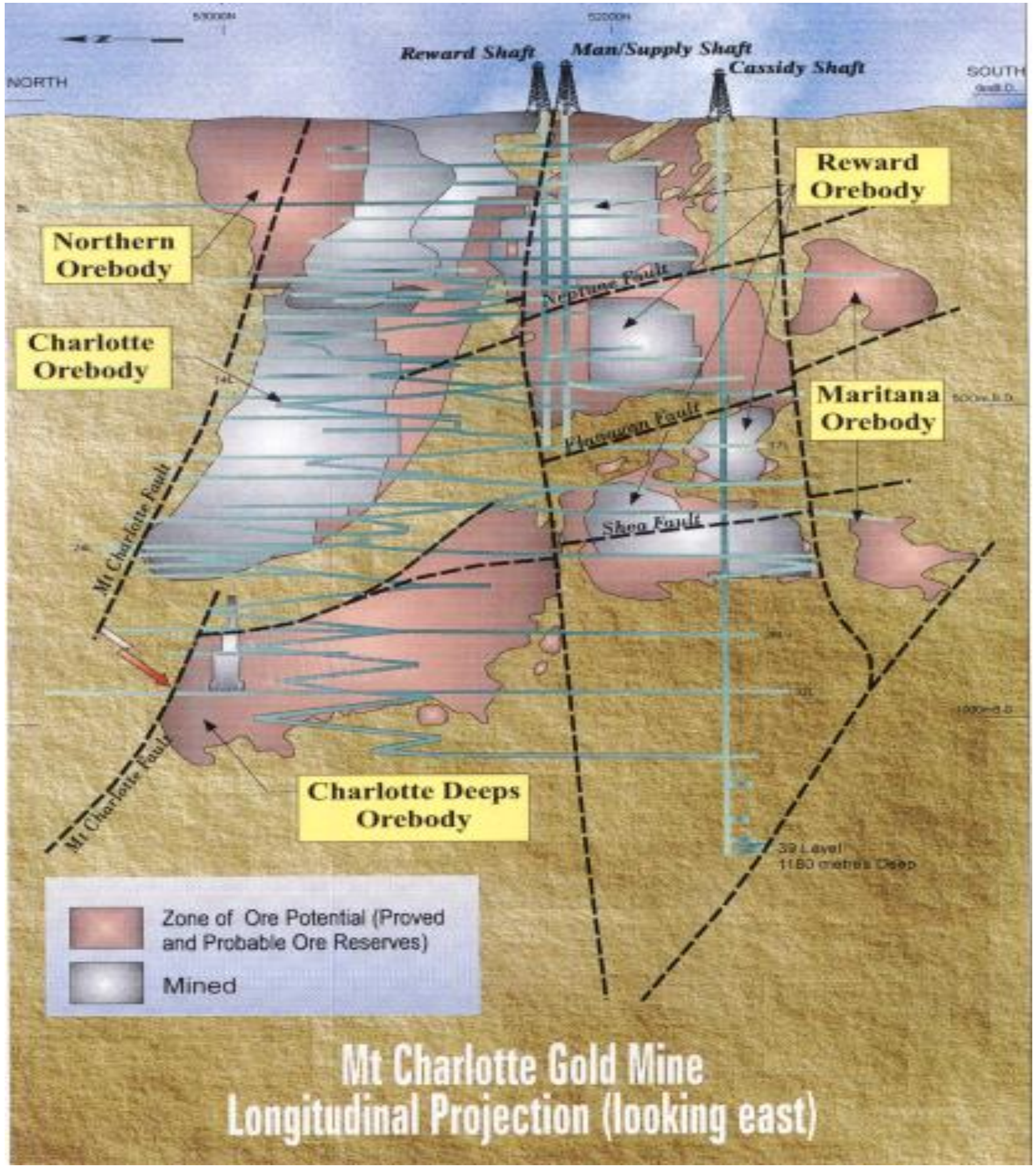
Super Pit, Kalgoorlie

Kalgoorlie
593km east of Perth



The access network of declines and shafts

Global mine optimisation

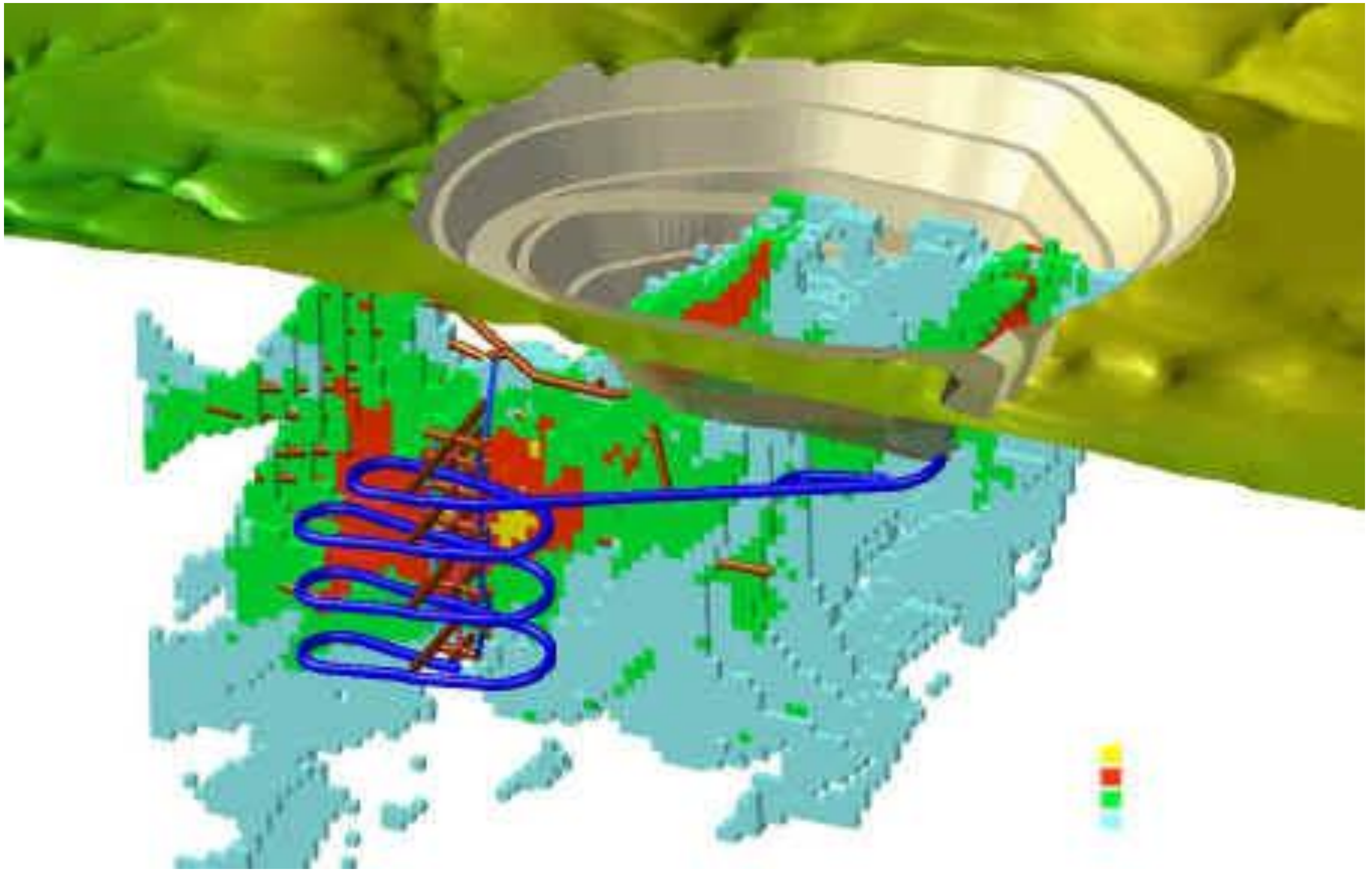
- Overarching aim is to maximise the value
- Current practice: open pit versus underground mine optimisation
- Ore vs waste. What cut-off grade and mining method?
- These decisions require consideration of many other aspects such as stope design, access, scheduling, production rates, net present value
- Constraints - geology, technical, financial
- Multiple scenarios need to be evaluated to tackle this global optimisation problem

Efficient infrastructure is key to profitable mining

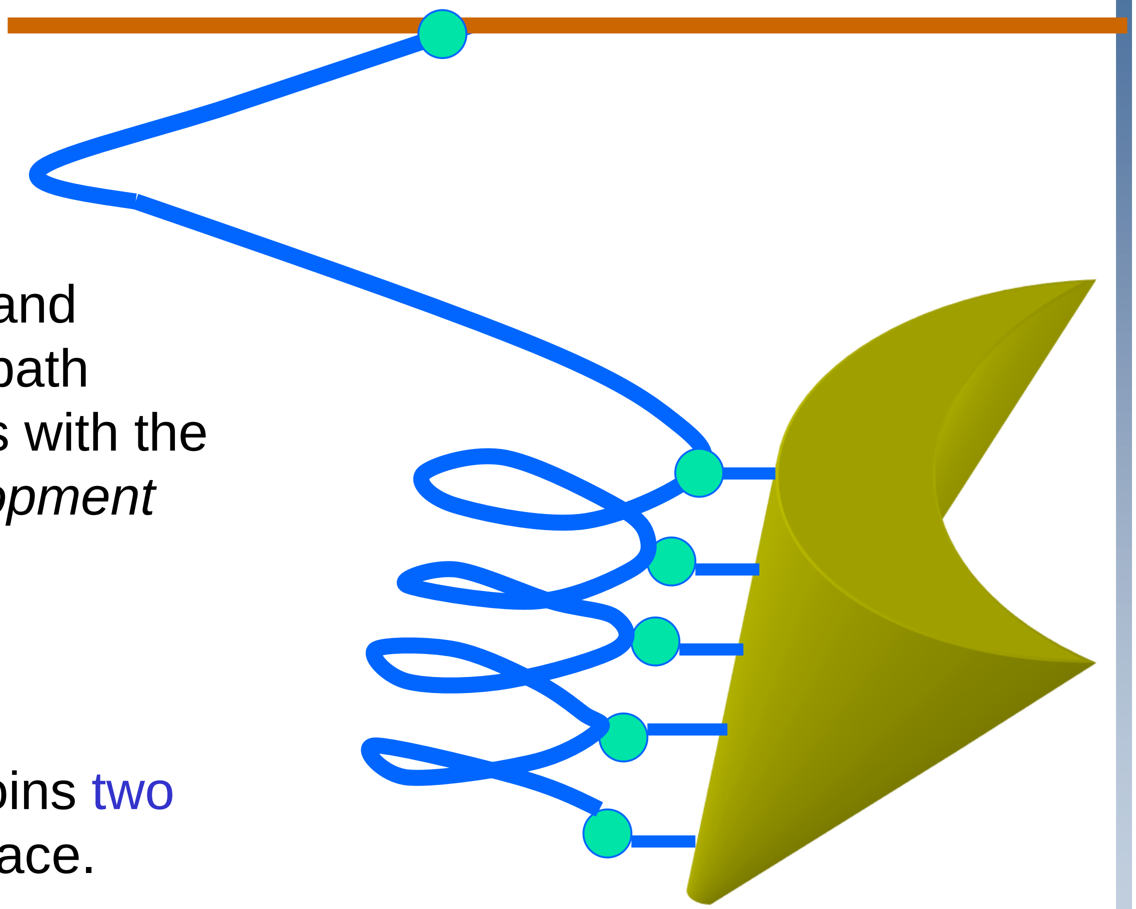
Navigability constraint on decline

Decline gradient: 1:7 to 1:9
Turning circle: a minimum turning radius for curved declines, 15m to 40m

Extension of an open pit mine via a decline



The mathematical model



Design task

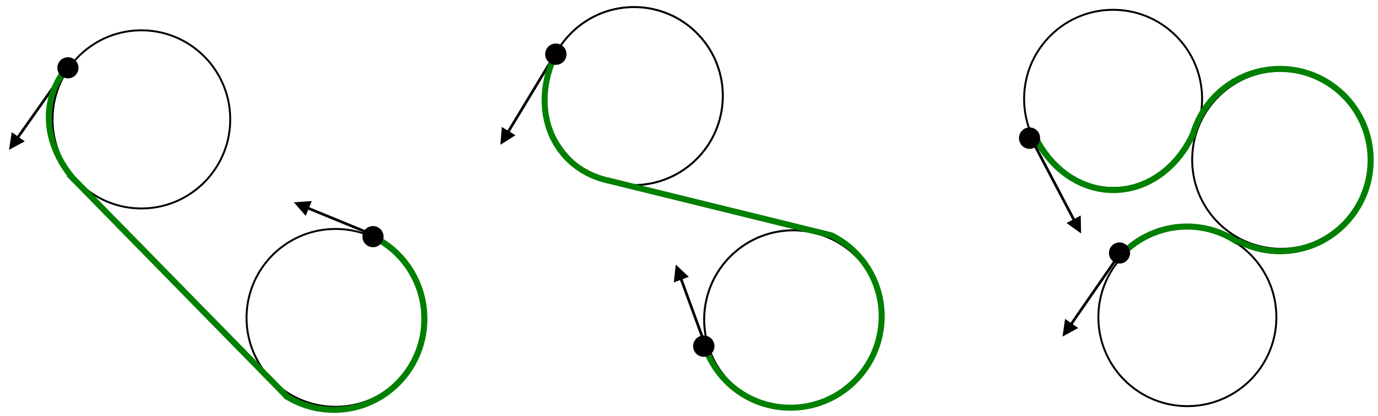
- Find a least cost gradient and turning circle constrained path linking given access points with the surface, minimising *development and haulage* costs.

Approach

- Find a shortest path that joins two given directed points in space.
- Use dynamic programming to stitch matching paths together.

Dubins Paths in the Plane

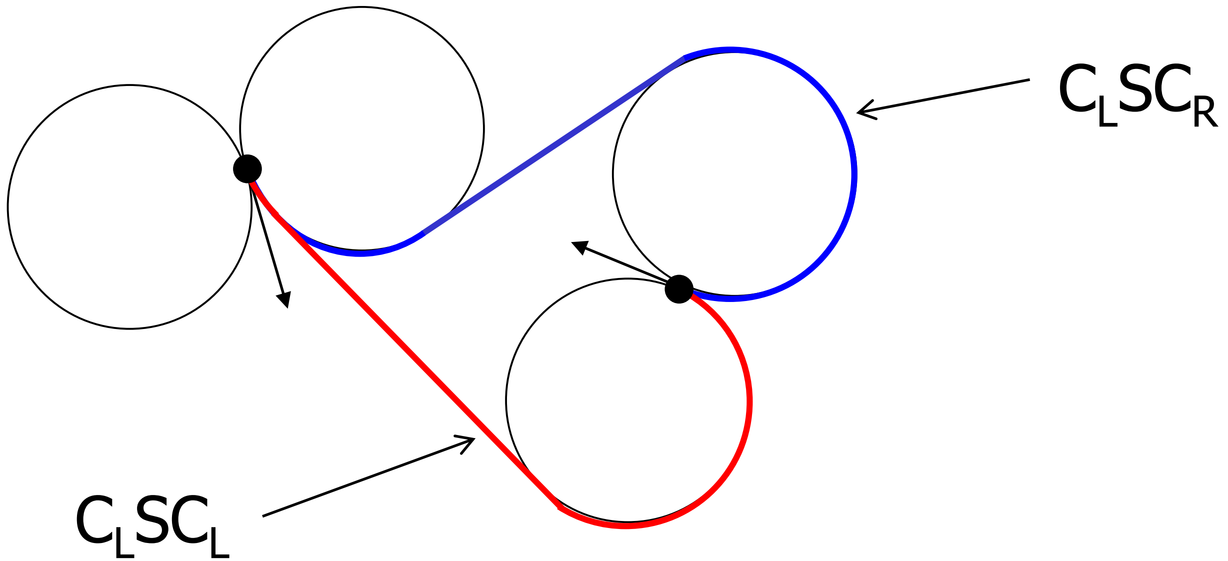
- Minimum length smooth curvature-constrained paths between two directed points in the plane have the forms CSC or CCC, where C corresponds to an arc of a circle with minimum radius of curvature *r*, and S to a line segment (Dubins, 1957).



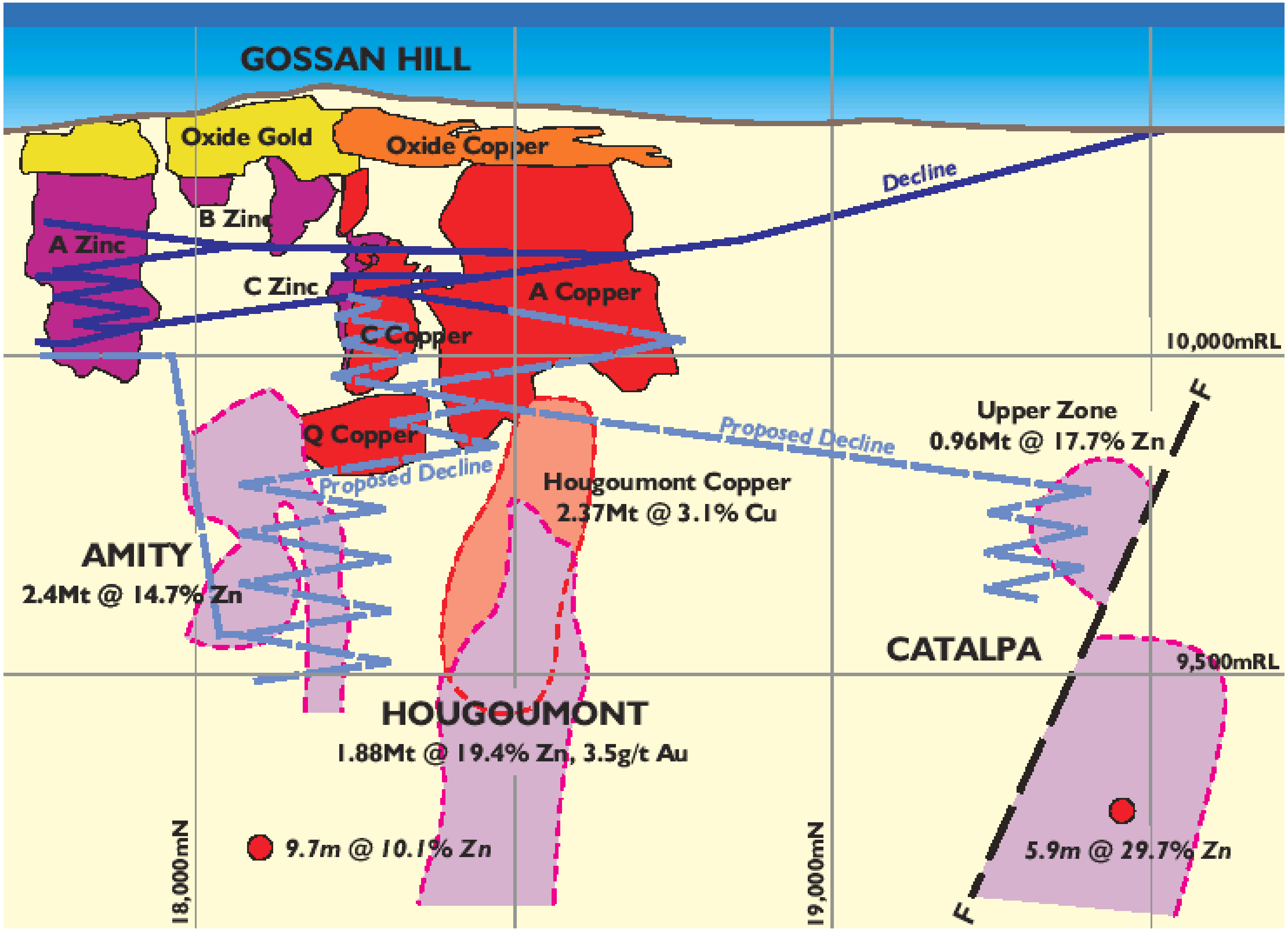
C_LSC_L C_LSC_R $C_LC_RC_L$

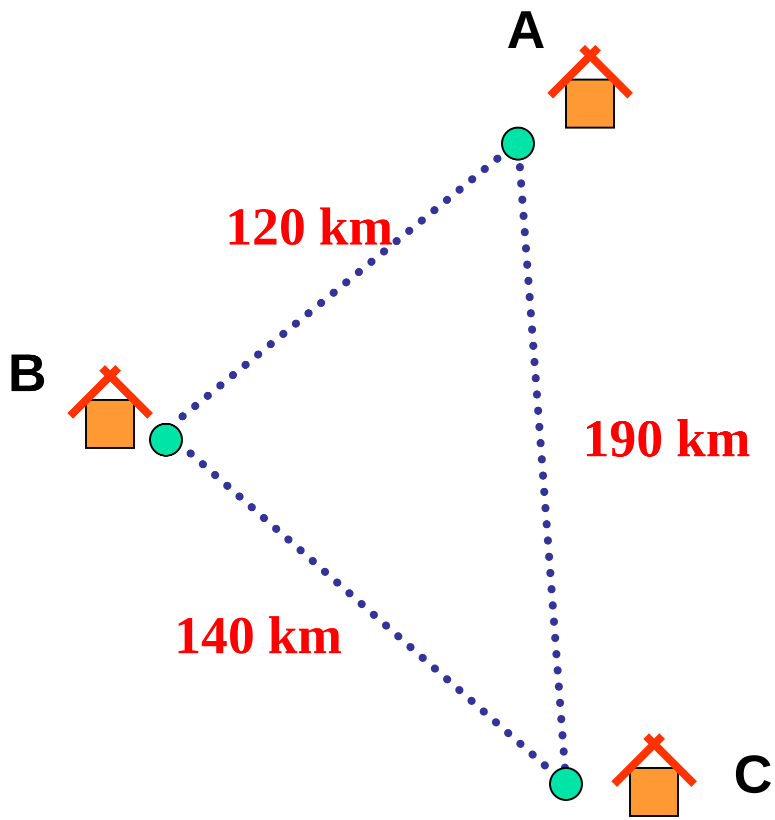
The algorithm

- Generate the (up to) 6 Dubins paths
- Check which is the shortest to obtain the optimal path
- Extend it into space, preserving the curvature constraint, and stitch the paths together to form the centre line of the decline

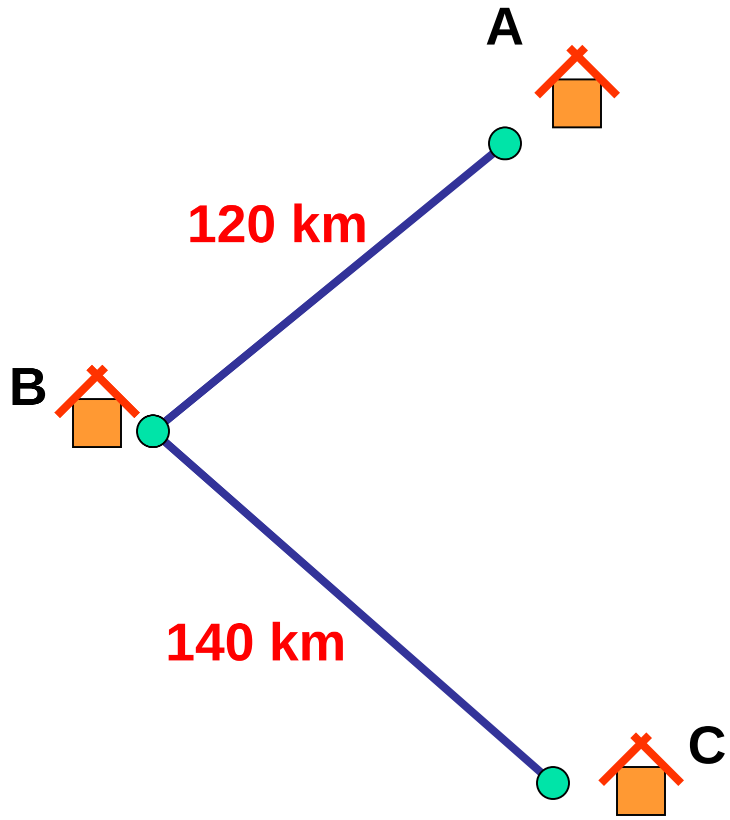


Example of an underground mining network

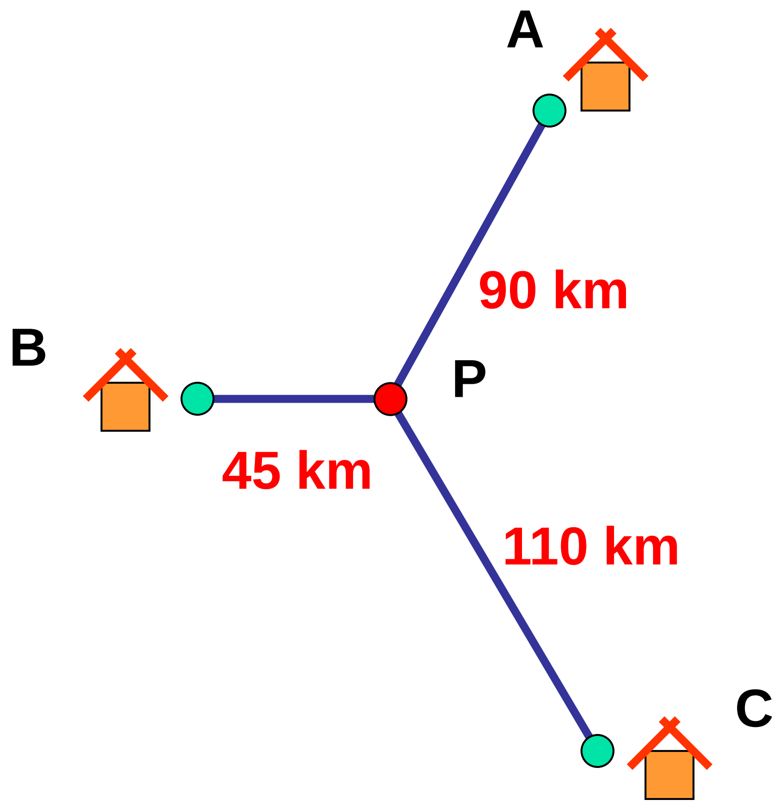




Three towns and their distances apart

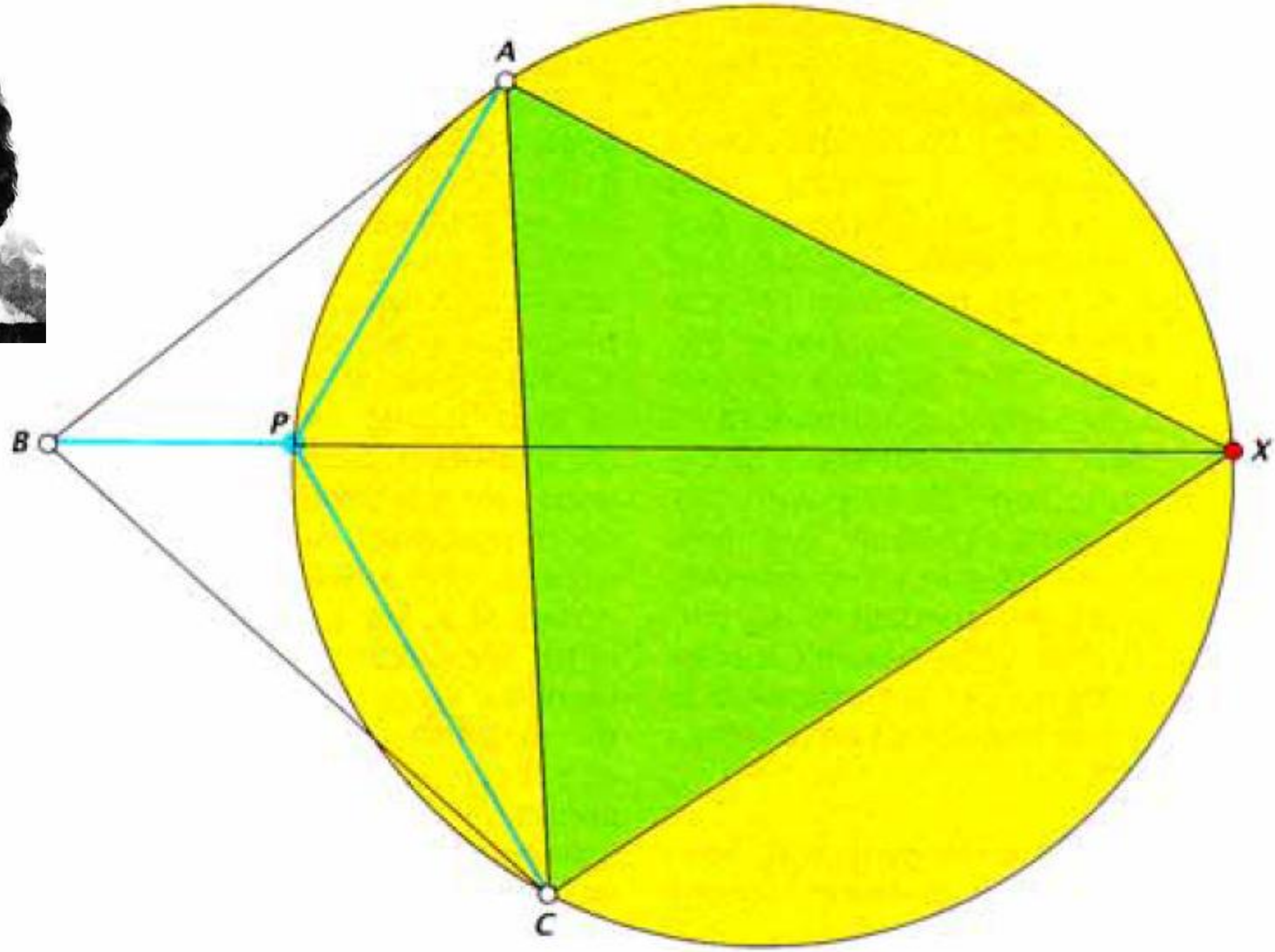


Network with length 260km

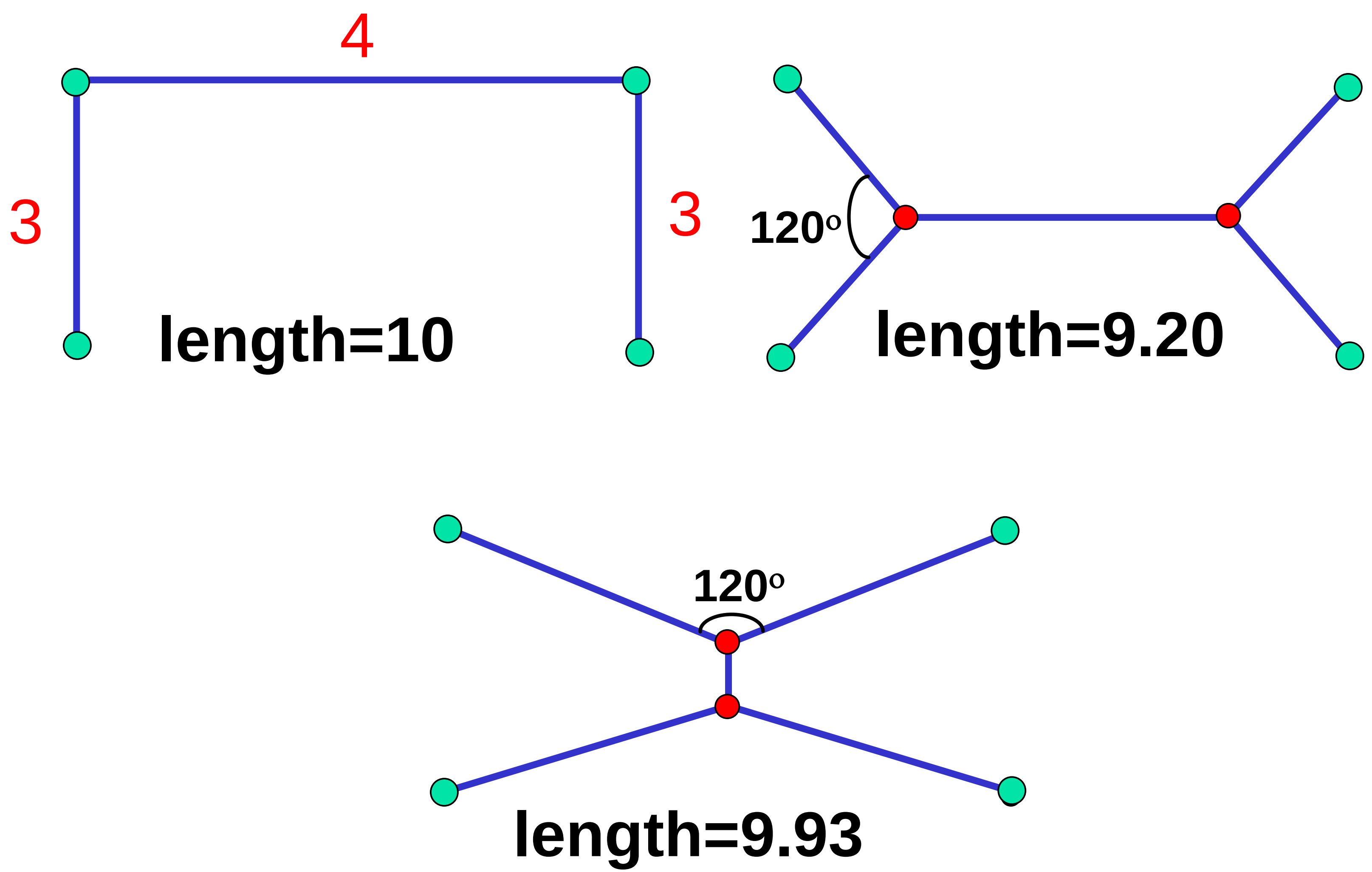


The shortest network has length 245 km

The construction to find the point *P*



Different possible connections for 4-point networks



The Shortest-Network Problem

(or Steiner Tree Problem)

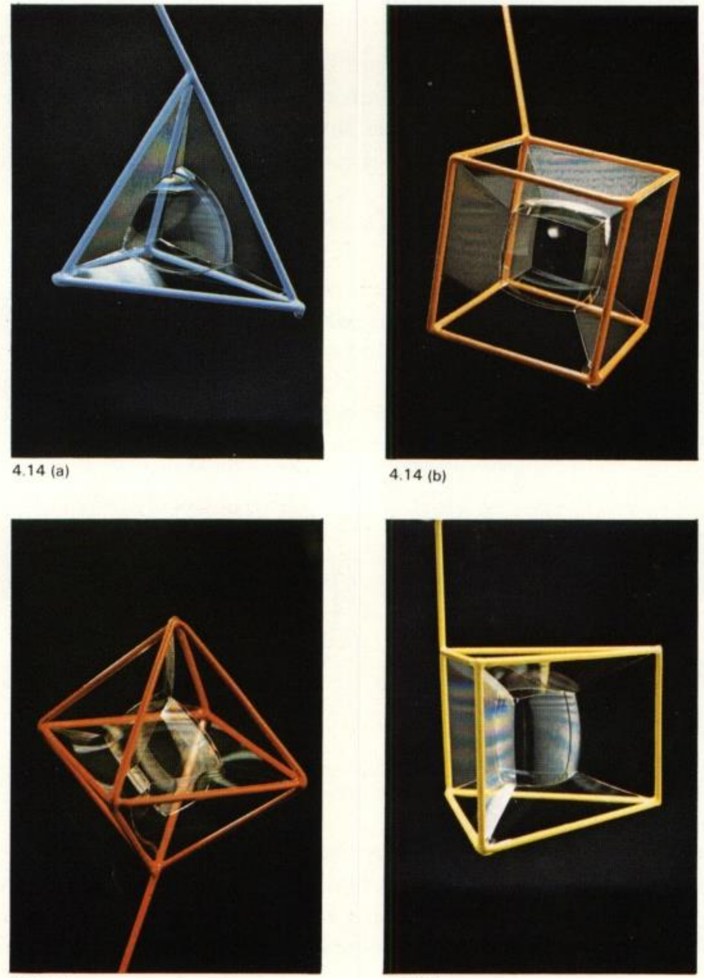
Consider a finite set of points in the Euclidean plane. The Steiner tree problem is to find the shortest network connecting these points.

For a given topology there are algorithms to find the position of the Steiner points. This gives a local minimum (Melzak 1960).

Because of the number and complexity of the possible Steiner topologies, the Steiner tree problem (to find the global minimum) is NP-complete.

Minimal surfaces

4.11

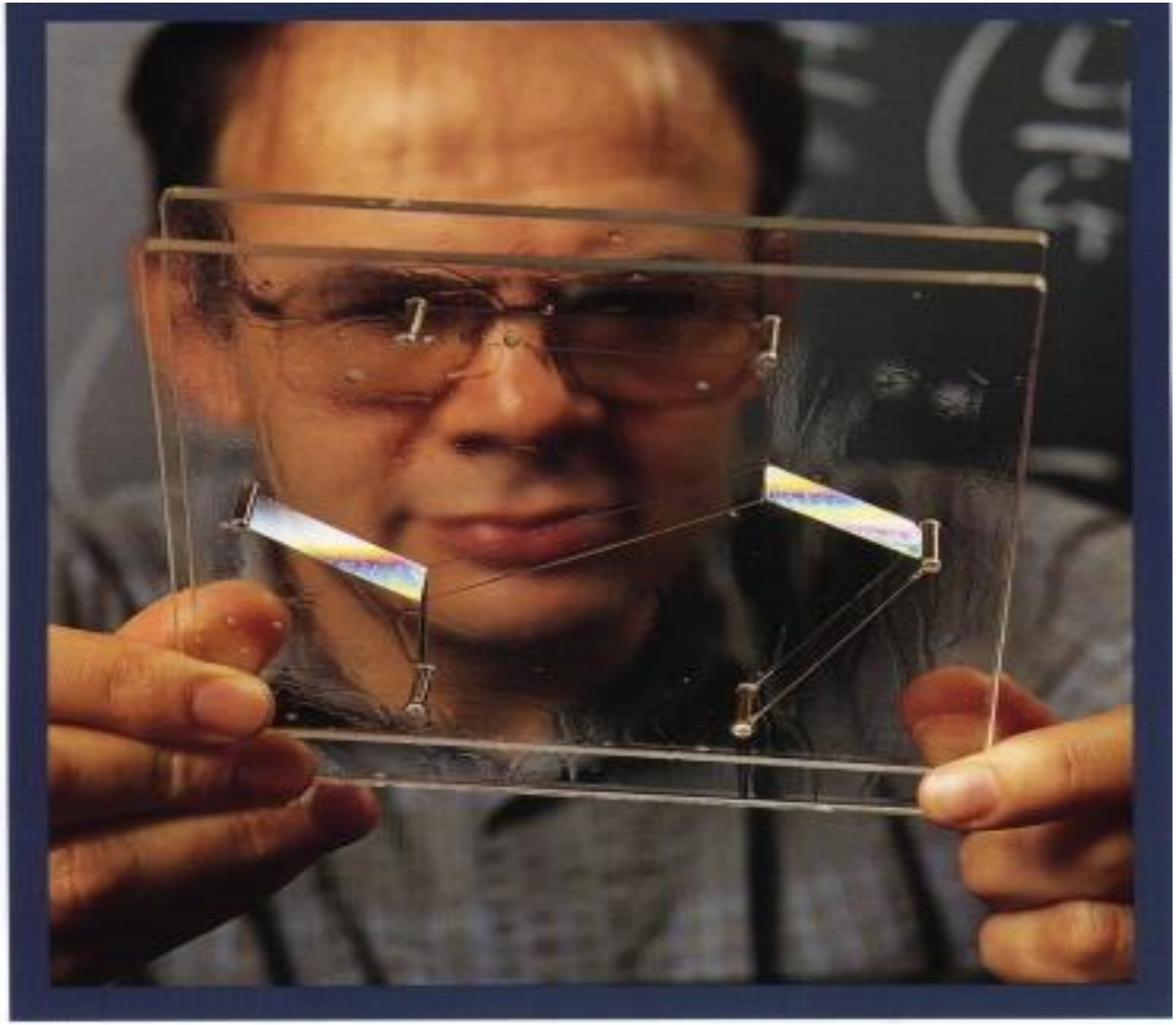


4.14 (a)

4.14 (b)

4.14 (c)

4.14 (d)



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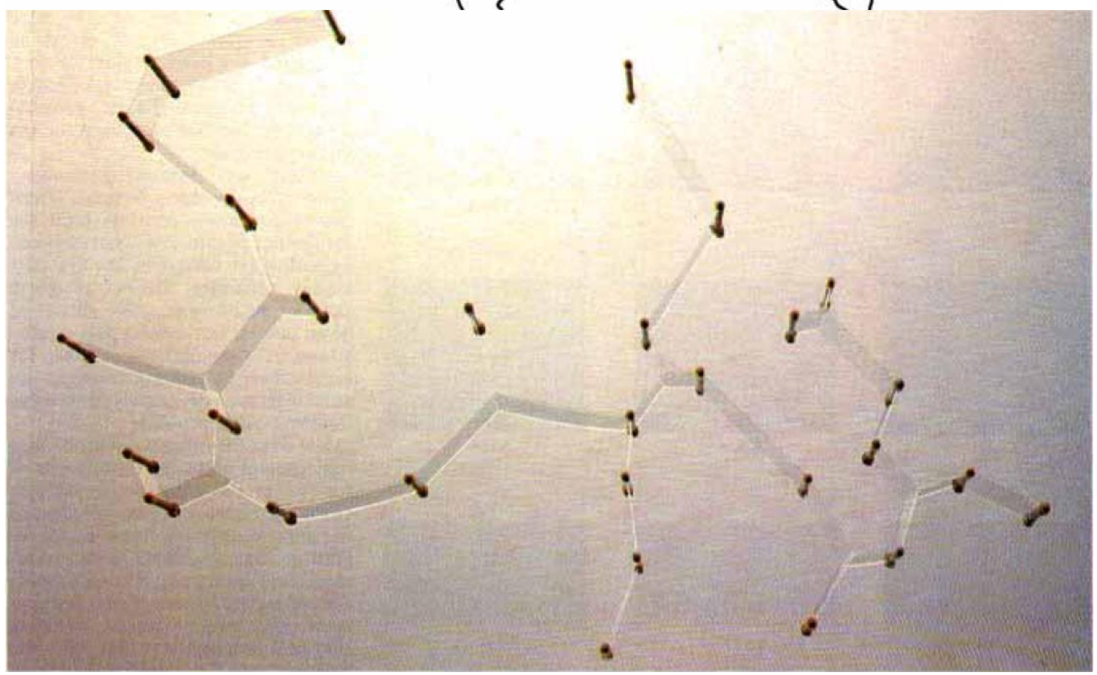
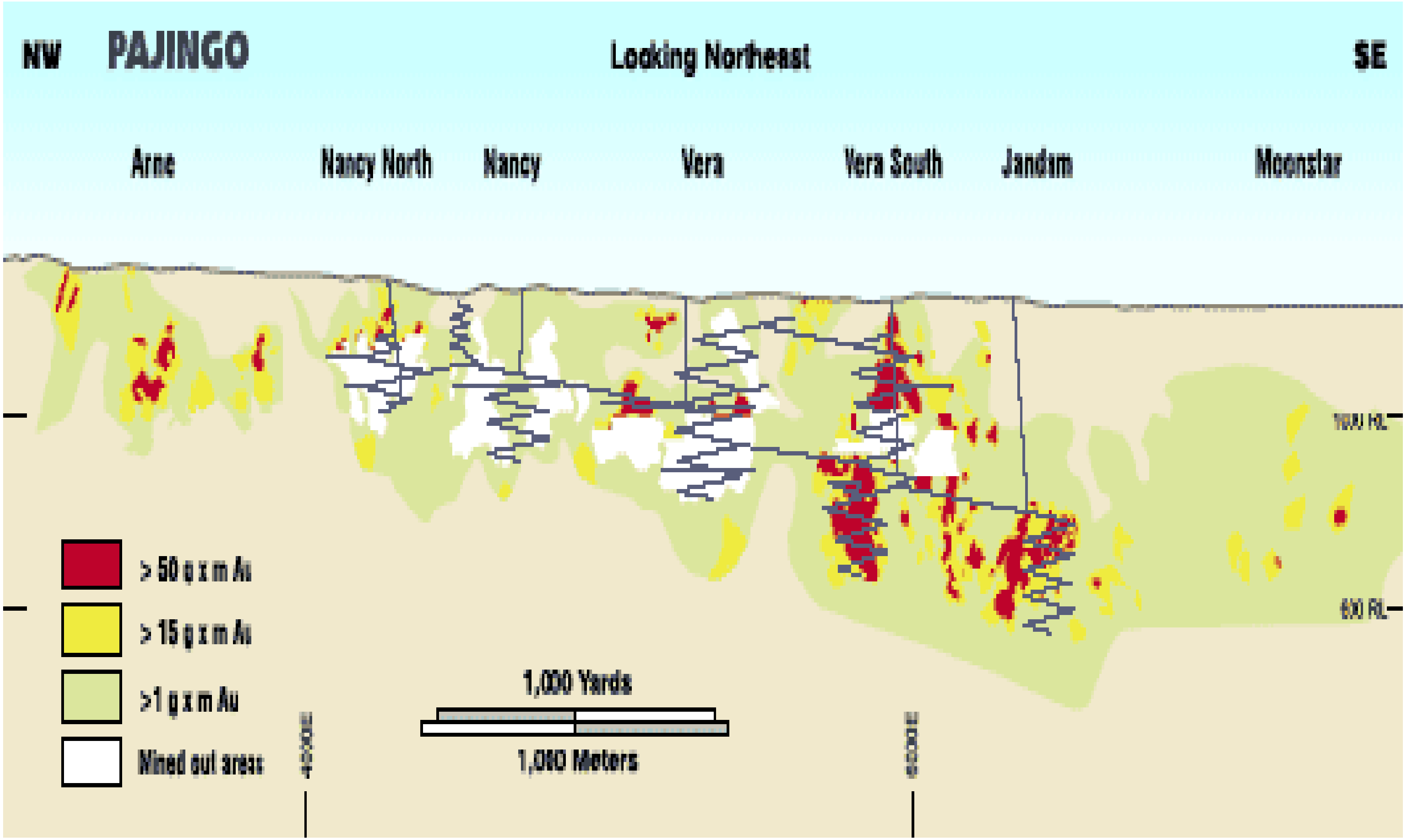
Soap bubble computer challenges electronic computer



Shortest network: 7,317 towns in Australia

Newmont's Pajingo gold mine



Problem description

- An underground mine is a system of tunnels connecting access points at fixed levels of the ore-zone with the surface portal (or break-out point of the existing mine).

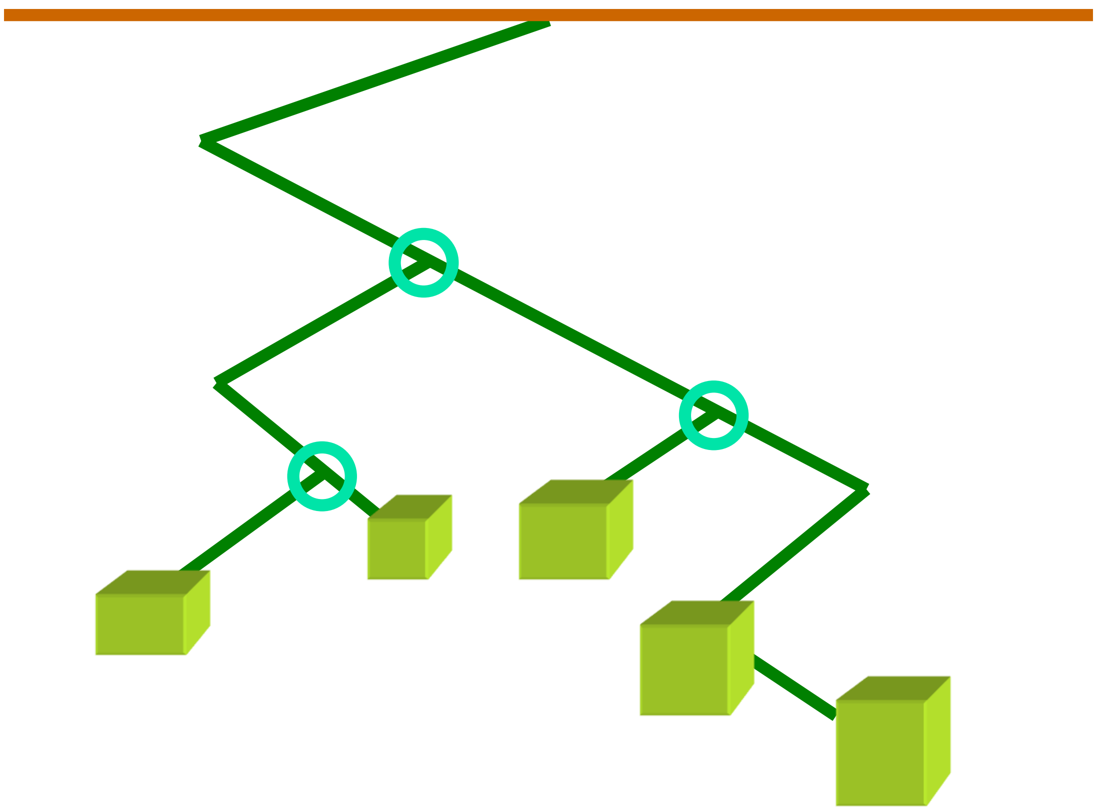
- The locations and tonnages of the ore-bodies and the locations of the access points are assumed to be given by mining engineers.

- The objective is to design a layout for the mine, connecting the access points and surface portal, that minimises the associated construction and haulage costs.

Model mine infrastructure as a weighted mathematical network

Nodes correspond to access points and surface portal

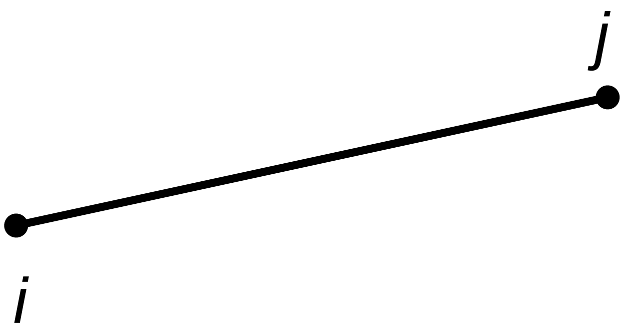
Links correspond to centreline of decline

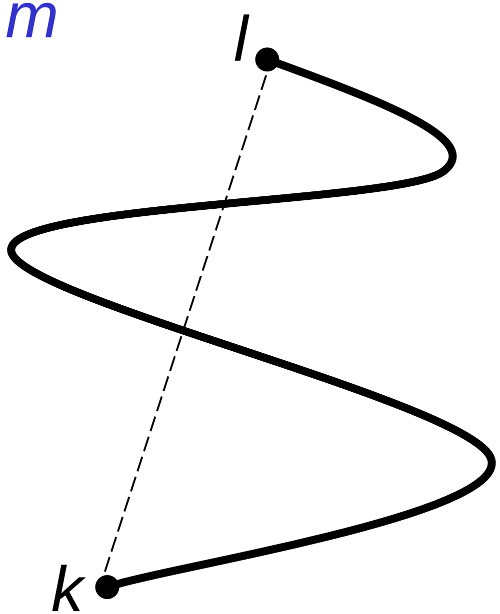


How long is a link? - The *gradient metric*

Gradient constraint

Links have gradient at most m





Gradient of (i,j) is $\leq m$

$L(i, j)$ is Euclidean length

Ramp (k,l) is a spiral of constant gradient m

$$L(k,l) = |z_l - z_k|\sqrt{1+m^{-2}}$$

Our solution method

For the 3-dimensional problem with gradient constraint:

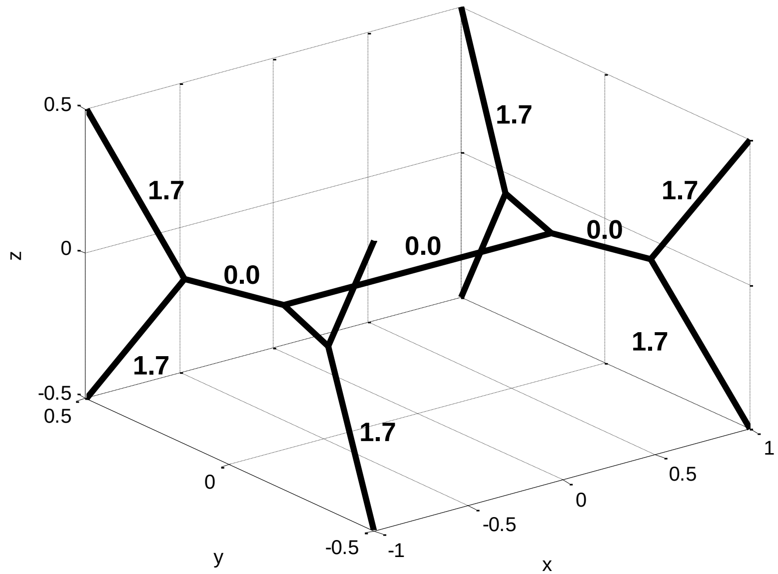
- New mathematics: Precise characterisation of minimal gradient-constrained networks with given topology.

- Gradient metric is convex (for given topology) - we use a descent method based on the characterisation of the minimal networks

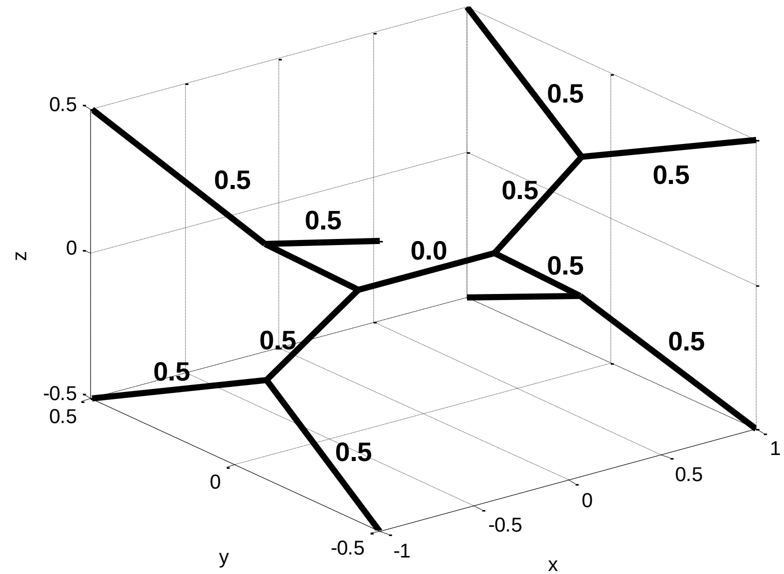
- Varying topologies treated with heuristic methods

Minimum length gradient-constrained trees

- Although exact algorithms exist in the plane, the problem in space is harder.
- Understanding the geometry of these minimum networks, has enabled us to solve this optimisation problem.

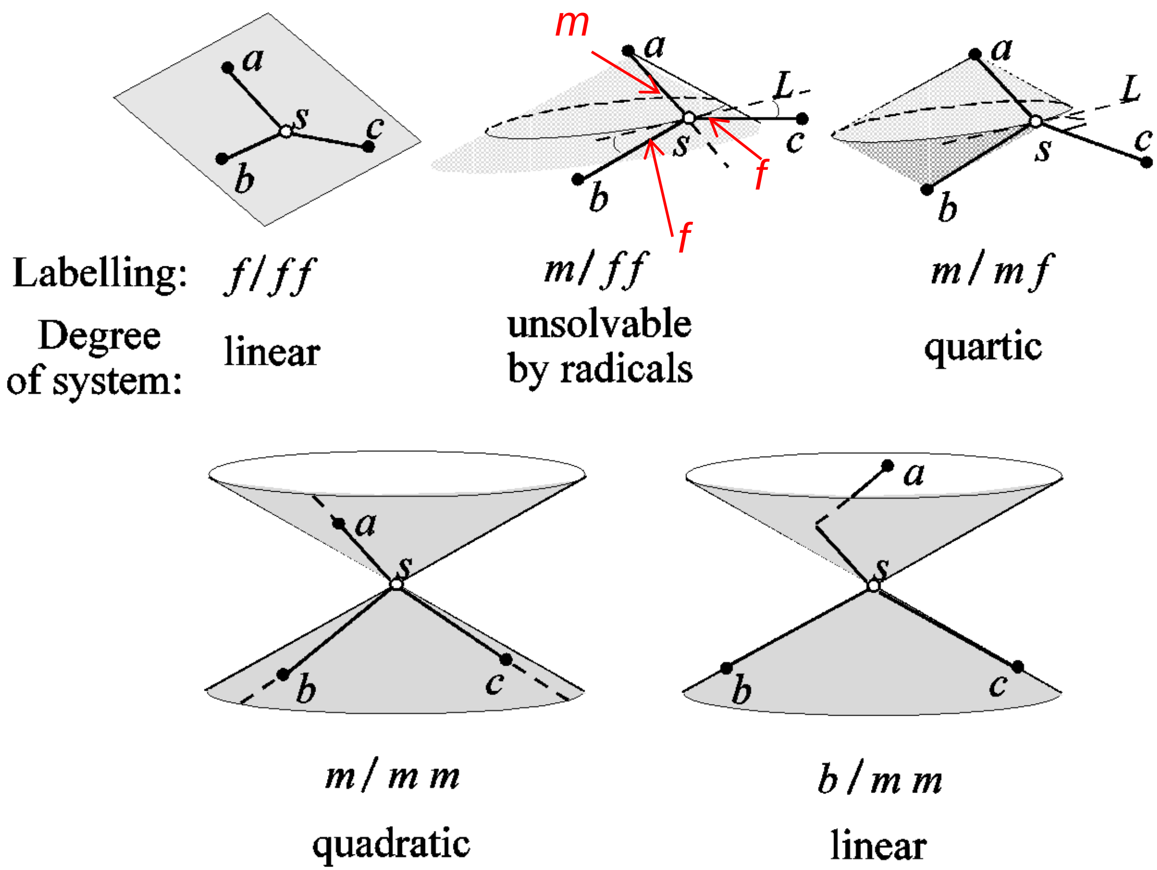


Not gradient-constrained

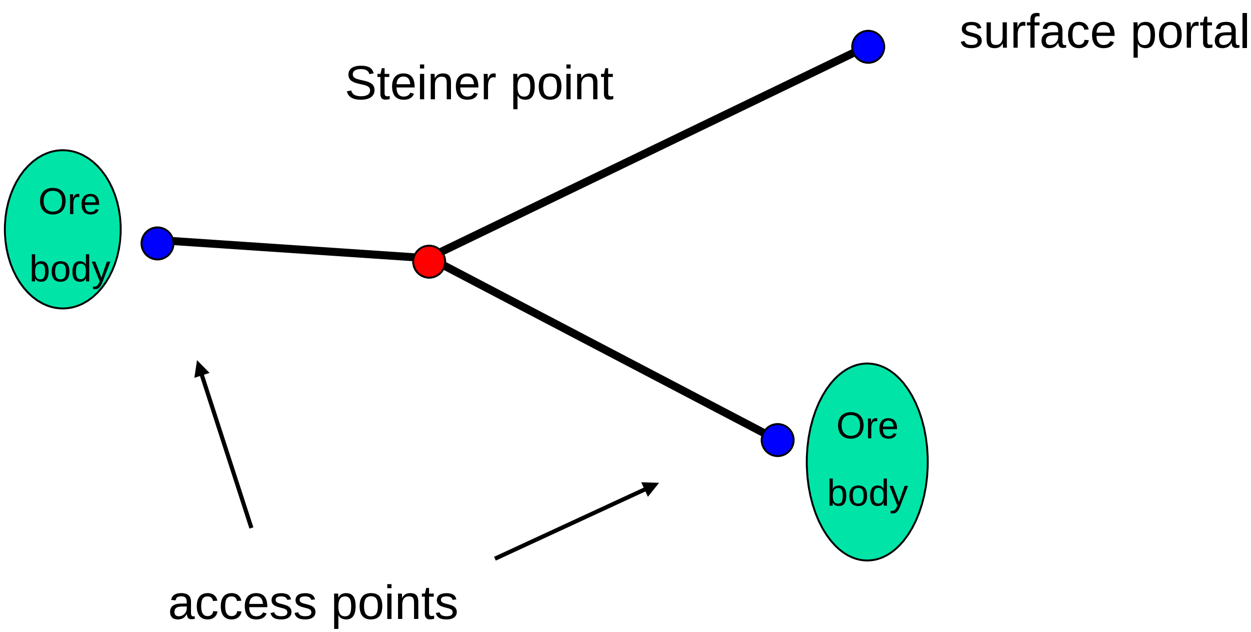


Gradient-constrained

The geometry: five feasibly optimal labellings for a Steiner point (up to symmetry)



Large tonnage links are more important when minimising combined access and haulage costs



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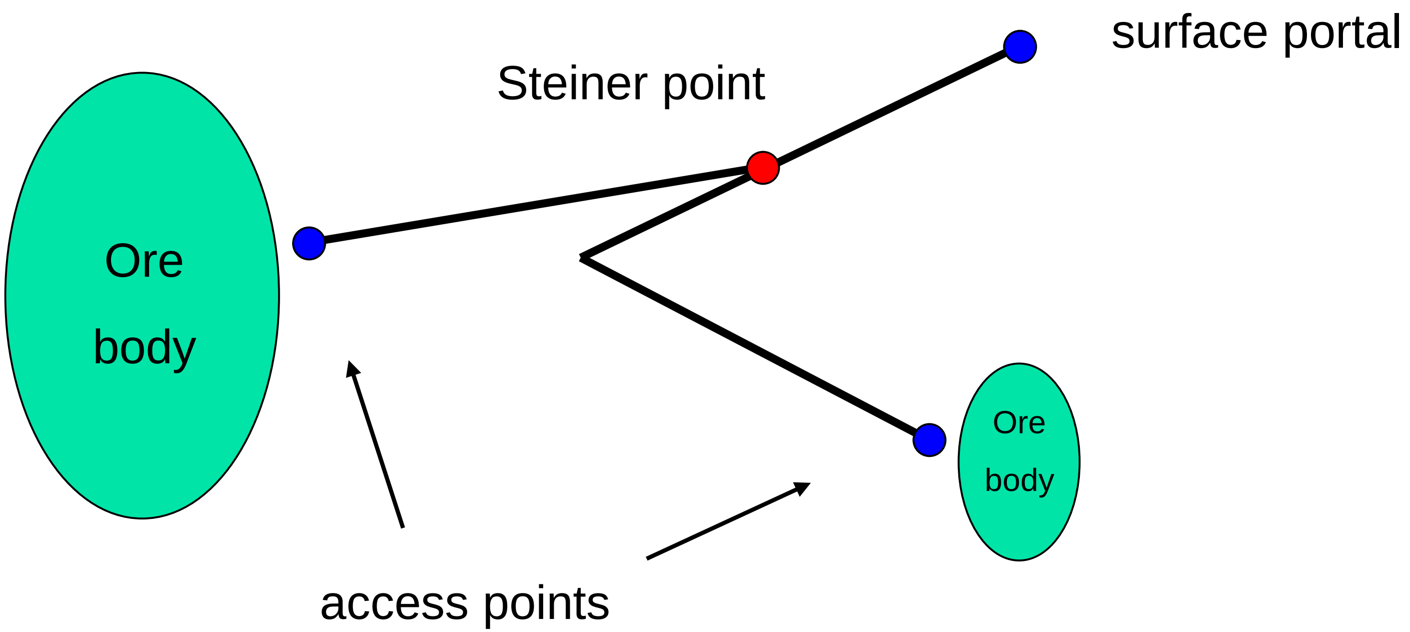
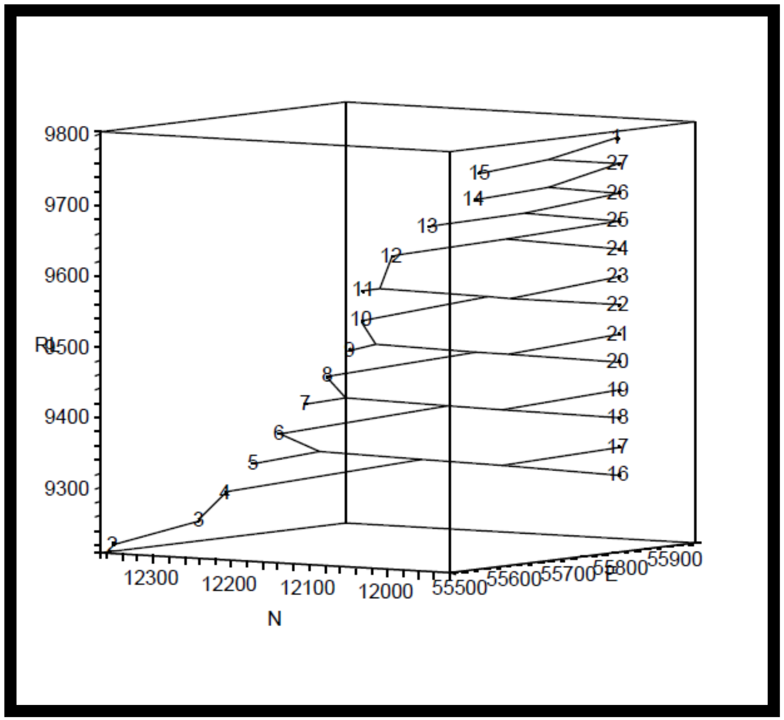


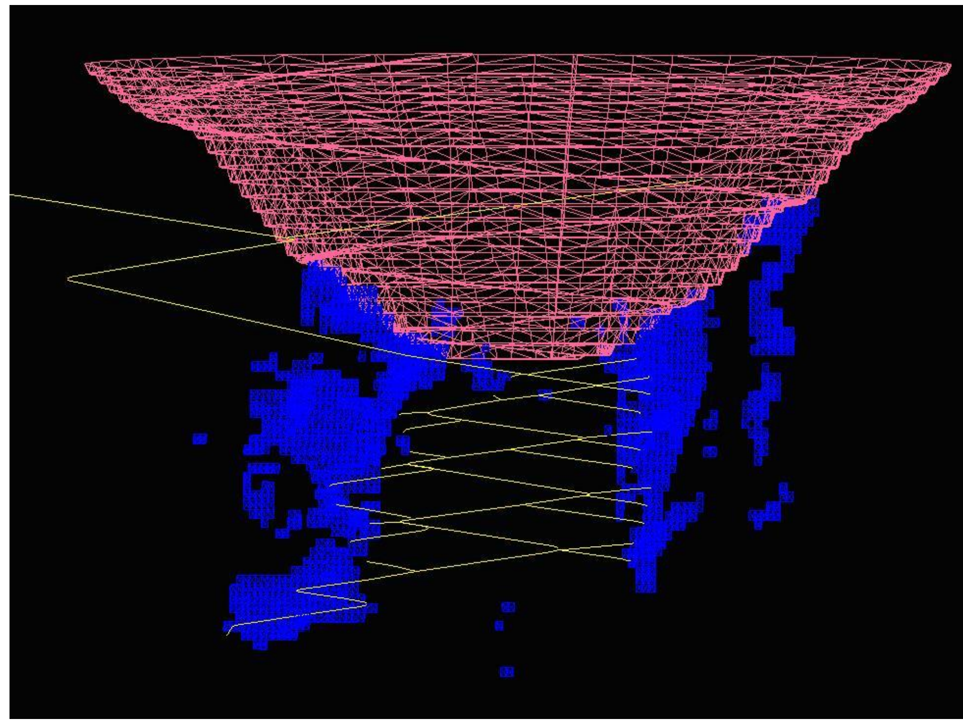
Decline Optimisation Tool, DOT

- DOT is a software tool that allows a mining engineer to design an optimal network of declines satisfying mine constraints and operational requirements, and minimises development and haulage costs.
- DOT allows an engineer to quickly and effectively test multiple options to determine the optimal decline design. This allows the engineer to consider alternative development options, based on practical requirements.
- MineOptima was spun off from the University of Melbourne with the DOT IP
- In 2017, Mineoptima was acquired by the mining software company RPM Global.

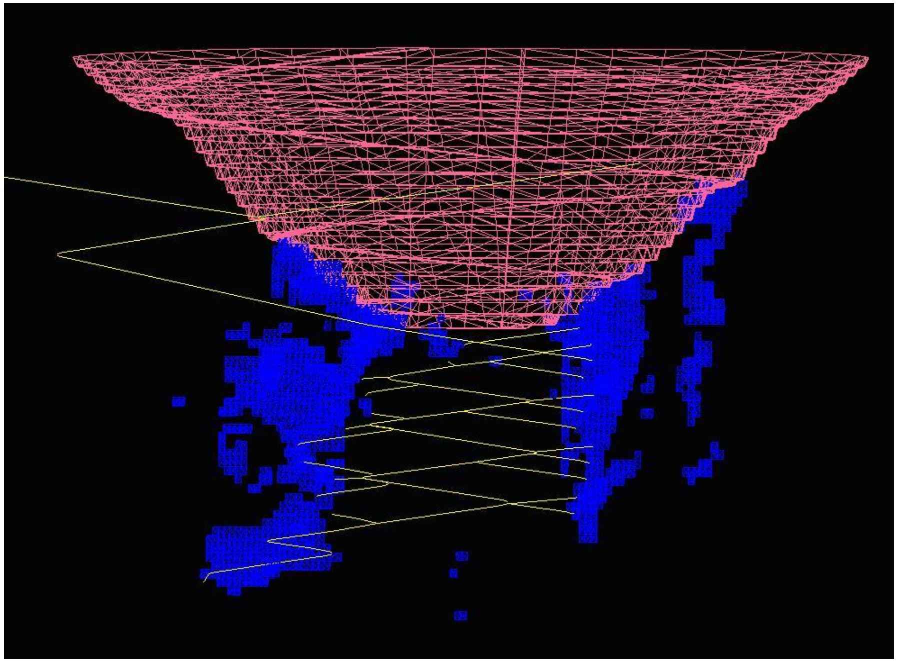
Prominent Hill being mined for copper and gold

Minimum topology for single decline

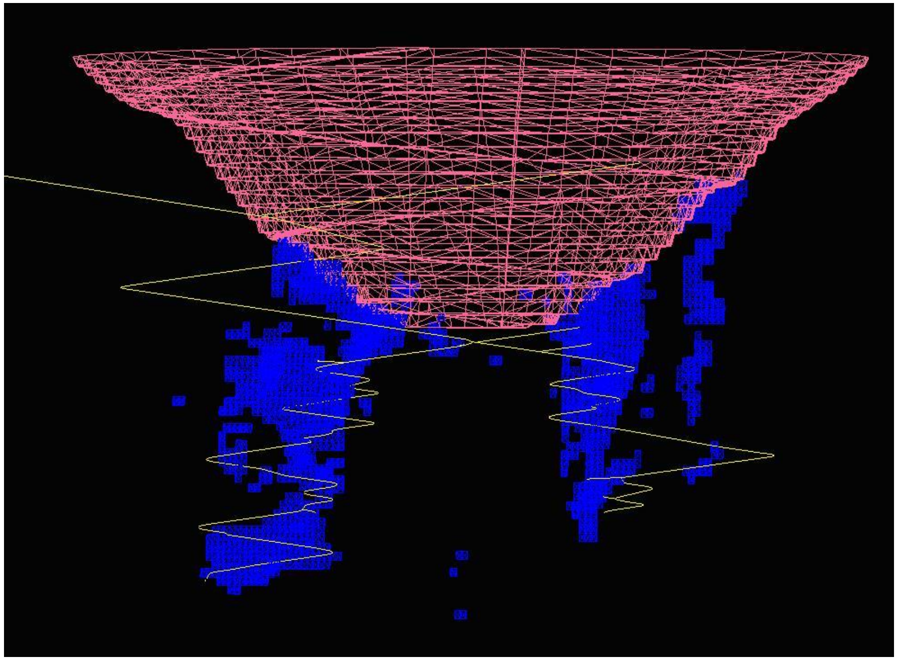




Strategic decline options for Prominent Hill



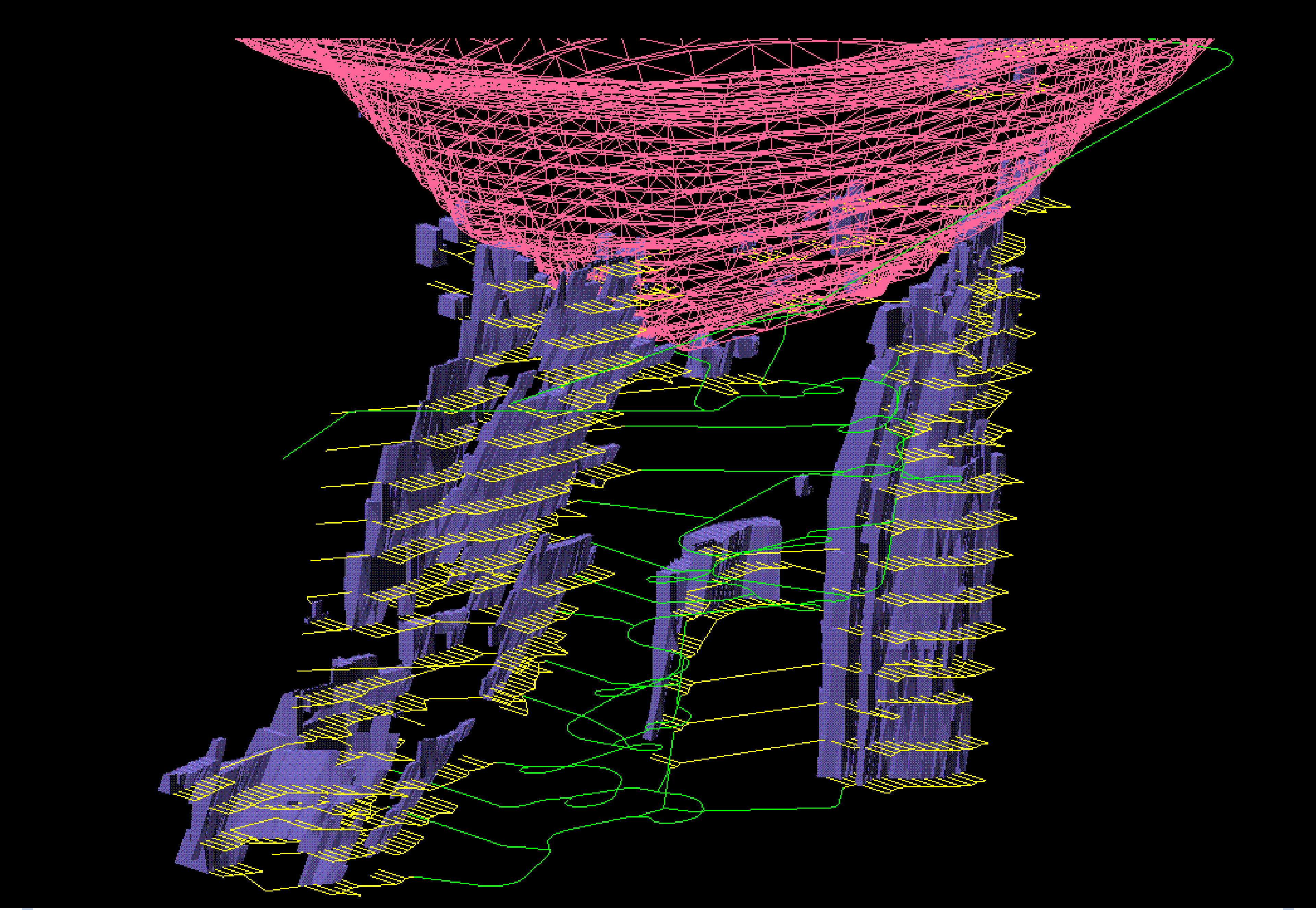
Single Decline



Double Decline

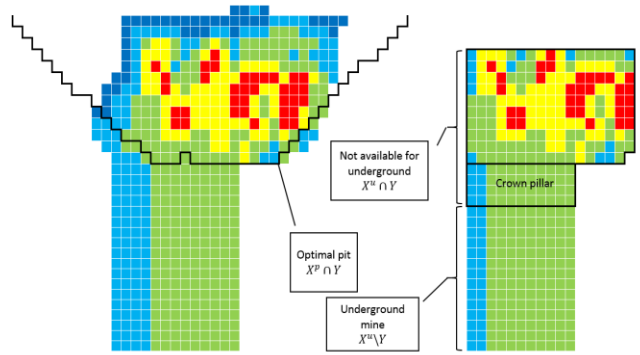
Orebodies divided into stopes with access

- Plan view of a level showing the stopes, primary and secondary (red and blue) as well as the access (yellow) into the stopes for blasting and mining.

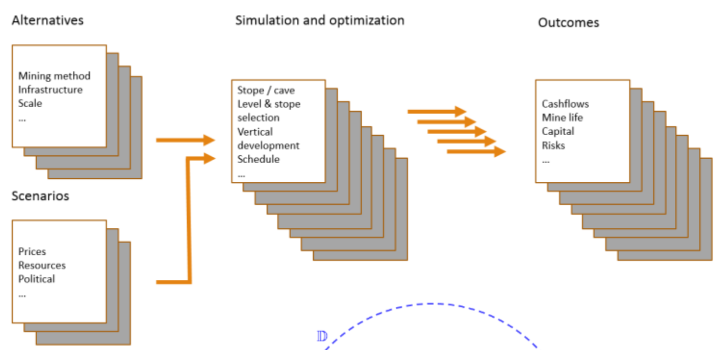


David Whittle's PhD outcomes

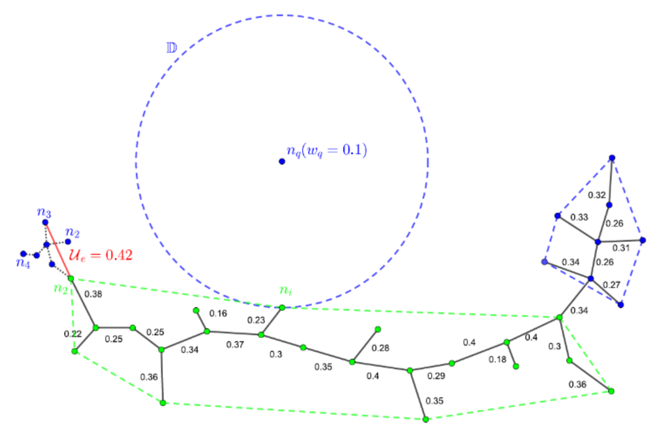
- Transition from open pit to underground mining - optimising the shape of the pit and the decision to transition underground, with a crown pillar



- Decompositions of the underground mine planning problem



- Prize collecting Euclidean Steiner tree problem-whether a stope is worth mining or should it be included in the network



Juan Yarmuch PhD outcomes:

- Modelling and including operational constraints into the open pit pushback design problem (to define a practical mining sequence). See Figure 1.
- Developing a new model and heuristic solutions for the optimisation of open pit ramp design. See Figure 2.

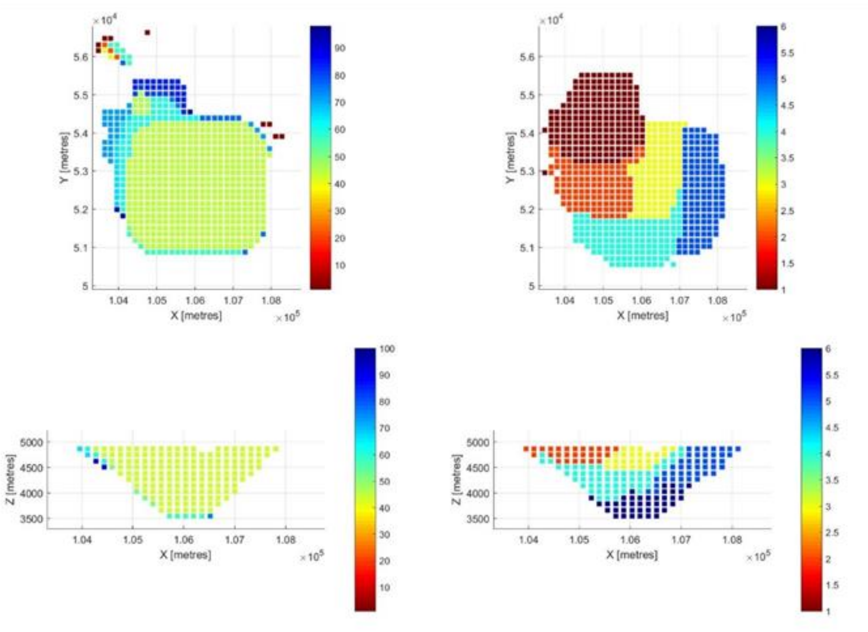


Figure 1: Nested pits (left). New model for practical pushbacks optimisation (right).

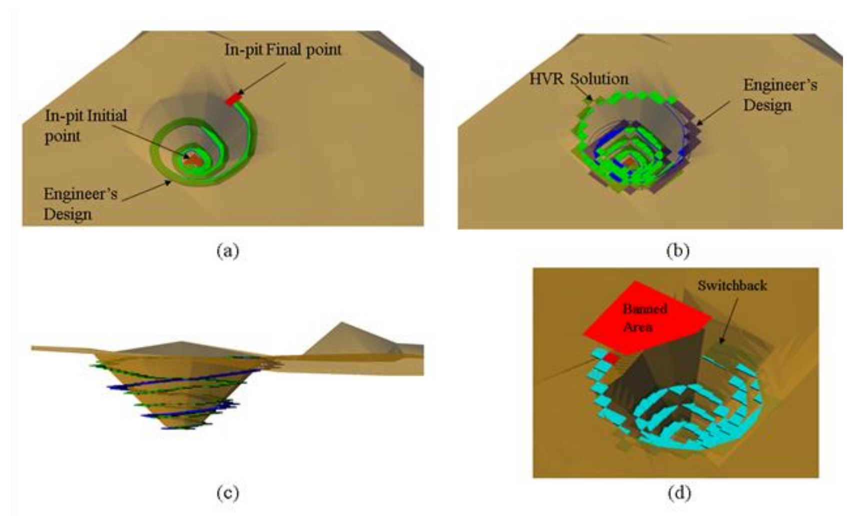


Figure 2: Optimal ramp design considering construction and haulage cost.

THANK YOU

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