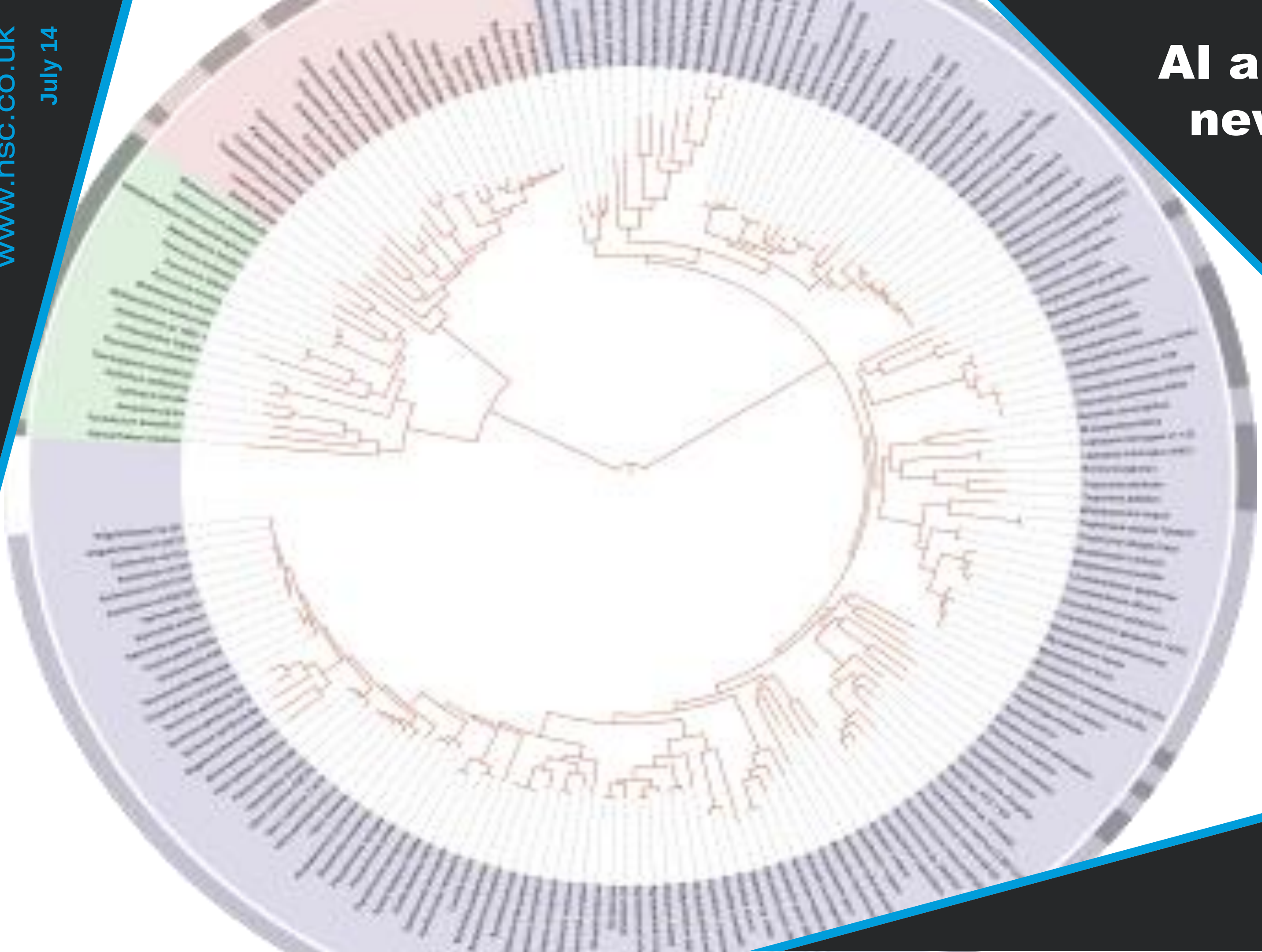
www.nsc.co.uk

July 14



# AI algorithms and new approaches to wargame simulation

S Lucek, NSC

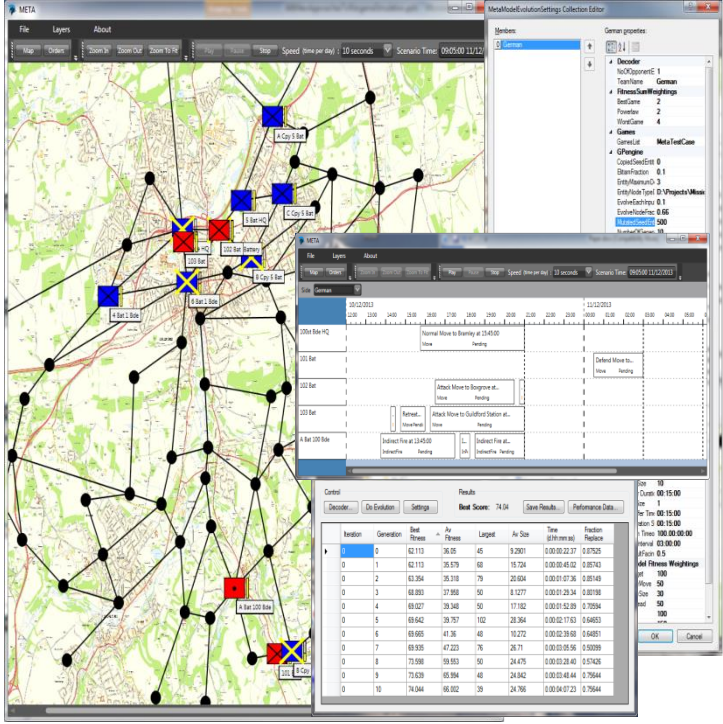
S Collander-Brown, Dstl

31 ISMOR

training • simulation • consultancy

# Overview

- Mission Planner: combat decision-making (AI) toolset
  - Supports Dstl high intensity warfighting simulations, to reduce/eliminate:
    - Complex pre-scripting
    - Human-in-the-loop
- Stochastic Optimisation AI
  - Genetic Programming, Simulated Annealing (novel approach)
  - Generic algorithms & architecture – Plug and Play
    - Simple application to different problems
- Formulate the problem: Military-like syntax
  - AI algorithms efficiently generate plans for tactical problems
    - Resemble human-like decision making
- META model - AI generates plans against a reduced problem set
  - Representing essential elements of the full problem.
  - Resulting solution evaluated against the full problem set
    - SimBrig assessing brigade level land engagements
  - Overcomes some of the limitations of AI techniques used



Speed (time per day) : 10 seconds
Scenario Time: 09:05:00 11/12/2013

Side German

| | 10/12/2013 12:00 – 23:00 | 11/12/2013 00:00 – 05:00 |
|---|---|---|
| 100st Bde HQ | Normal Move to Bramley at 15:45:00<br>Move Pending | |
| 101 Bat | | Defend Move to...<br>Move Pending |
| 102 Bat | Attack Move to Boxgrove at...<br>Move Pending | |
| 103 Bat | Retreat...<br>MovePendi<br>Attack Move to Guildford Station at...<br>Move Pending | |
| A Bat 100 Bde | Indirect Fire at 13:45:00<br>IndirectFire Pending<br>I...<br>InA<br>Indirect Fire at...<br>IndirectFire Pending | |

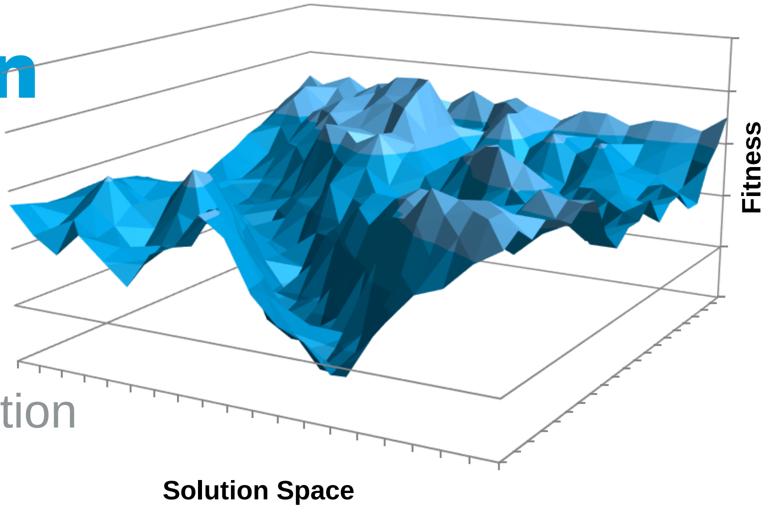
Decoder
NoOfOpponentE 1
TeamName German
FitnessSumWeightings
BestGame 2
Powerlaw 2
WorstGame 4
Games
GamesList MetaTestCase
GPengine
CopiedSeedEntit 0
ElitismFraction 0.1
EntityMaximumD 3
EntityNodeTypeI D:\Projects\Missi
EvolveEachInpu 0.1
EvolveNodeFrac 0.66
MutatedSeedEnt 500
NumberOfGenes 10
Size 10
Durati 00:15:00
ize 1
fer Tim 00:15:00
ation S 00:15:00
Timeo 100.00:00:00
nterval 03:00:00
ltFacin 0.5
del Fitness Weightings
et 100
Move 50
Size 30
ead 50
100

Best Score: 74.04

| Iteration | Generation | Best Fitness | Av Fitness | Largest | Av Size | Time (d.hh:mm:ss) | Fraction Replace |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 62.113 | 36.05 | 45 | 9.2901 | 0.00:00:22.37 | 0.87525 |
| 0 | 1 | 62.113 | 35.579 | 68 | 15.724 | 0.00:00:45.02 | 0.85743 |
| 0 | 2 | 63.354 | 35.318 | 79 | 20.604 | 0.00:01:07.36 | 0.85149 |
| 0 | 3 | 68.893 | 37.958 | 50 | 8.1277 | 0.00:01:29.34 | 0.80198 |
| 0 | 4 | 69.027 | 39.348 | 50 | 17.182 | 0.00:01:52.89 | 0.70594 |
| 0 | 5 | 69.642 | 39.757 | 102 | 28.364 | 0.00:02:17.63 | 0.64653 |
| 0 | 6 | 69.665 | 41.36 | 48 | 10.272 | 0.00:02:39.68 | 0.64851 |
| 0 | 7 | 69.935 | 47.223 | 76 | 26.71 | 0.00:03:05.56 | 0.50099 |
| 0 | 8 | 73.598 | 59.553 | 50 | 24.475 | 0.00:03:28.40 | 0.57426 |
| 0 | 9 | 73.639 | 65.994 | 48 | 24.842 | 0.00:03:48.44 | 0.75644 |
| 0 | 10 | 74.044 | 66.002 | 39 | 24.766 | 0.00:04:07.23 | 0.75644 |

nsc
training • simulation • consultancy

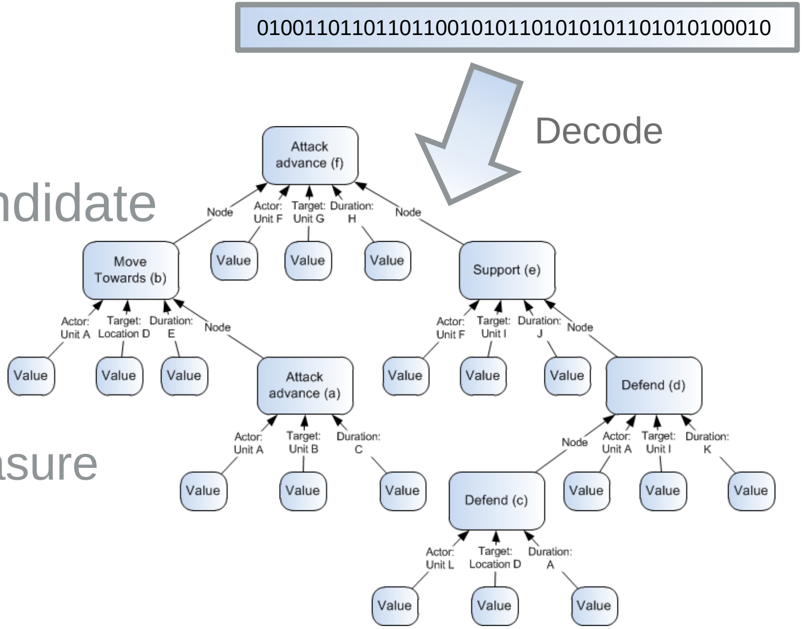
# Stochastic Optimisation



- Family of techniques for solving any generalised problem
- Complex problem
  - Finds good but not guaranteed best solution
  - Explores whole solution space not just locally good solution
- Explore solution space in controlled way
  - Based on fitness measure
  - Definition of “good” can vary with user requirement
- Wide range of problems
  - Timetabling/Scheduling (travelling salesmen)
  - Game solutions (chess/soccer bots)

training • simulation • consultancy

# Genetic Algorithms



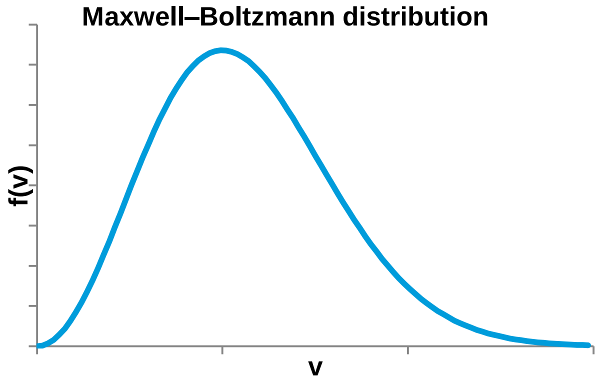
- Entity – abstract representation of a candidate solution to a problem
  - Typically bit stream
  - Decoded to a solution
  - Solution evaluated to obtain fitness measure
- Population of Entities
  - Initialise randomly
  - Evolve in generations, mutation, parent crossover & selection effects mimic survival of fittest
- End with a ‘best’ solution
- Genetic Programming
  - Ensures efficient decoding

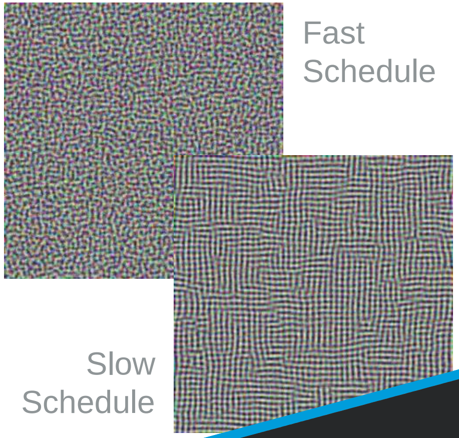
# Fitness measure

- Core of all Stochastic Optimisation algorithms
- Good measure of fitness
  - Allows algorithm to correctly apply selection pressure
  - Ensures fittest elements of population are evolved
- Each entity represents order set
  - Run through game & assess results
    - Losses
    - Achievements (positions held or denied from the enemy, or enemy losses or neutralisation)
    - Risk (enemy proximity, own units mutually supporting)
    - Efficiency (minimum resource consumption)
- SO algorithms notorious for finding loopholes

# Simulated Annealing

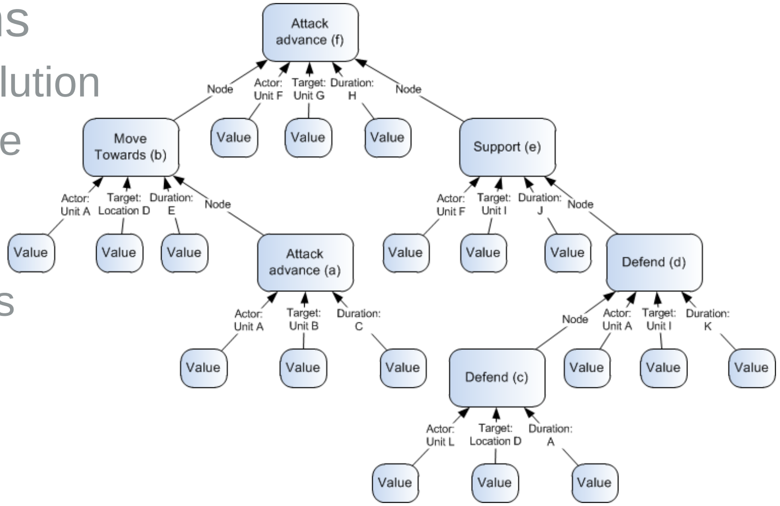
- Well understood & efficient optimisation technique
- Candidate solution
  - Randomly perturbed for new solution
  - Probability new solution accepted:
  - $e^{-\frac{F_C - F_N}{T}}$
  - T: “Temperature”
  - F: Fitness measure – Well understood/constrained
- Annealing Schedule
  - Initially large T – explore solution space
  - As progress – reduce T to “polish” good solution





# SA: Solution Perturbation

- Problem in application to gaming problems
  - How to perturb candidate solution for new solution
  - Efficient algorithm should consider T schedule
    - Large perturbations for high T
    - Small perturbations for low T
  - Node/Input tree of GP solution easy to do this
  - Perturbation
    - Node: select node in tree
      replace with randomly generated node tree
    - Input: change input value(s)
  - High T
    - Favour Node perturbation
    - Favour Nodes with many descendants
    - Change multiple Inputs

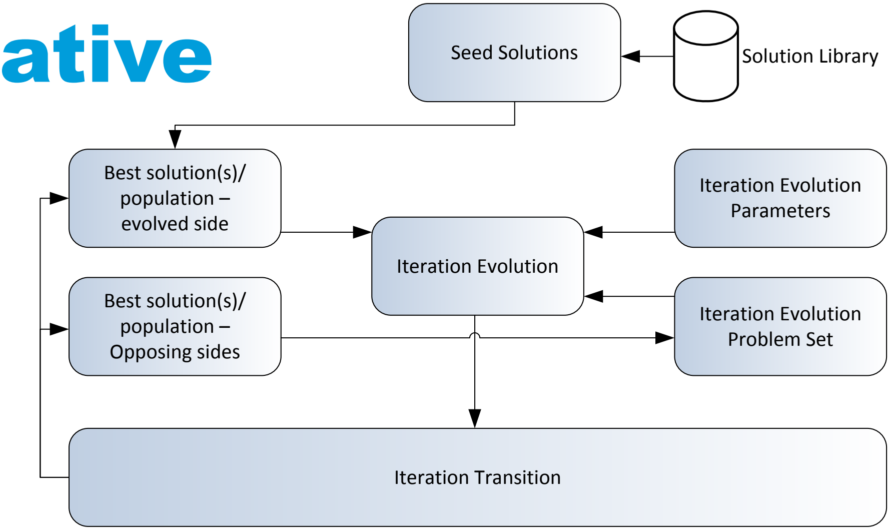


training • simulation • consultancy

# Stochastic Optimisation: limitations

- Slow – consider many solutions
- Solutions are problem specific:
  - Only optimises based on fitness criteria
    - Excellent at novel solutions tailored to detail of problem
      - Not doctrinally correct solution found in Staff Officers Handbook
    - Exploits loopholes
      - In fitness criteria
      - In evaluation model
        - Good test for model

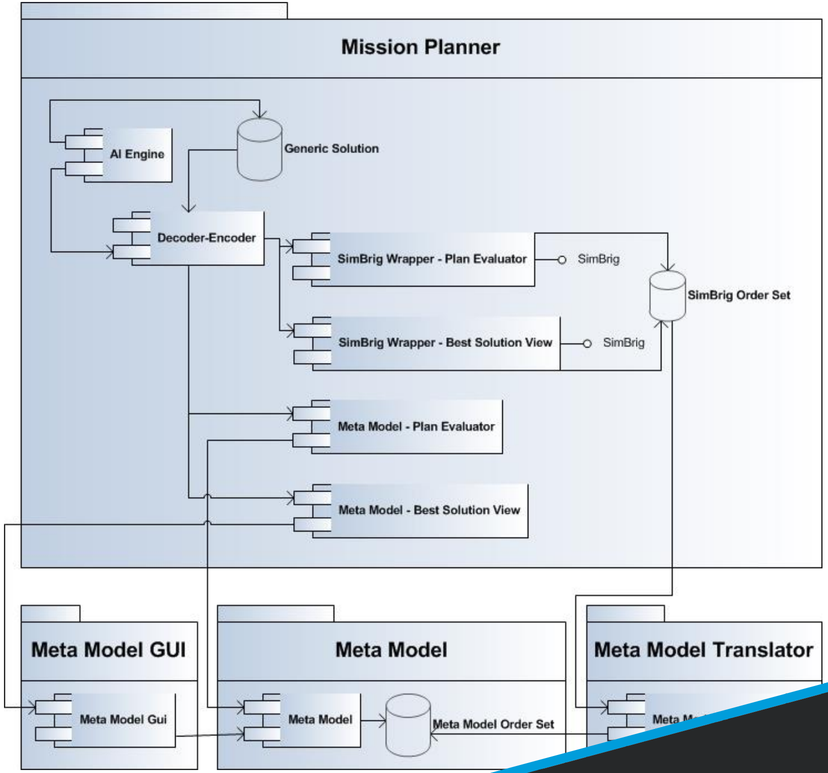
# Mission Planner: Iterative


Seed Solutions
Solution Library
Best solution(s)/ population – evolved side
Iteration Evolution Parameters
Iteration Evolution
Best solution(s)/ population – Opposing sides
Iteration Evolution Problem Set
Iteration Transition

- Generate/evolve best solution
- Next iteration, use last iteration best solution &
  - Change side
  - Change problem scenario
  - Change AI algorithm control parameters
- Solution can be evolved against multiple scenarios
  - Must be good against each
- Solution can be seeded
  - Library of solutions

# Mission Planner: Generic

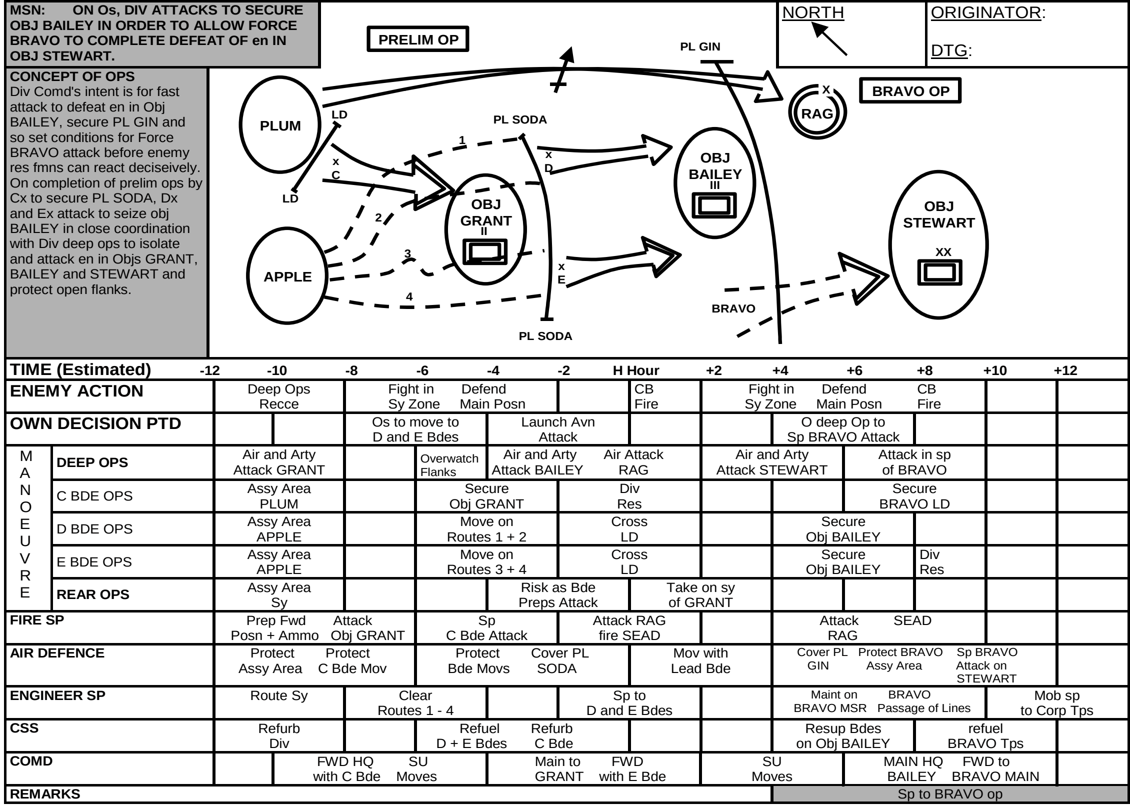
- AI algorithms Generic Solution
  - Nodes and inputs have no meaning
  - No concept of problem applied to
  - Simply randomly changed
- Decoder
  - Only problem specific part
  - Translates generic node tree to order set
  - Runs evaluation model to get fitness score
- Architecture: plug and play decoders
    - Proof of Concept
    - SimBrig
    - META
  - Iterations can use different decoder
  - Generate end solution using different decoder



training • simulation • consultancy

# Military Syntax

- Military Synch Matrix
- Nodes correspond to:
  - Areas
  - Timelines
  - Orders
    - Seize, Hold etc.
    - Linked to Areas & Timelines
- Units naturally co-operate in time and space
- Efficiently generate “human-like” orders



MSN: ON Os, DIV ATTACKS TO SECURE OBJ BAILEY IN ORDER TO ALLOW FORCE BRAVO TO COMPLETE DEFEAT OF en IN OBJ STEWART.

NORTH

ORIGINATOR:

DTG:

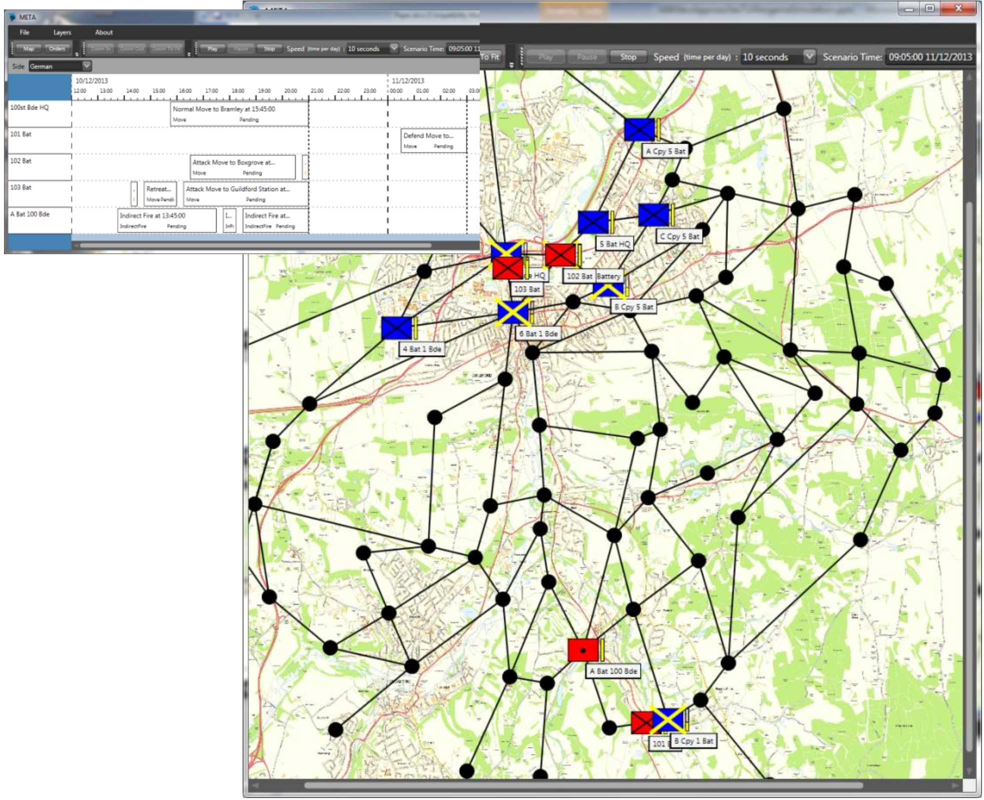
CONCEPT OF OPS

Div Comd's intent is for fast attack to defeat en in Obj BAILEY, secure PL GIN and so set conditions for Force BRAVO attack before enemy res fmns can react deciseively. On completion of prelim ops by Cx to secure PL SODA, Dx and Ex attack to seize obj BAILEY in close coordination with Div deep ops to isolate and attack en in Objs GRANT, BAILEY and STEWART and protect open flanks.

| TIME (Estimated) | | -12 | -10 | -8 | -6 | -4 | -2 | H Hour | +2 | +4 | +6 | +8 | +10 | +12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ENEMY ACTION | | Deep Ops Recce | | Fight in Sy Zone<br>Defend Main Posn | | | | CB Fire | Fight in Sy Zone<br>Defend Main Posn<br>CB Fire | | | | | |
| OWN DECISION PTD | | | | Os to move to D and E Bdes | | Launch Avn Attack | | | | O deep Op to Sp BRAVO Attack | | | | |
| MANOEUVRE | DEEP OPS | Air and Arty Attack GRANT | | | Overwatch Flanks | Air and Arty Attack BAILEY<br>Air Attack RAG | | | Air and Arty Attack STEWART | | Attack in sp of BRAVO | | | |
| | C BDE OPS | Assy Area PLUM | | | Secure Obj GRANT | | Div Res | | | | Secure BRAVO LD | | | |
| | D BDE OPS | Assy Area APPLE | | | Move on Routes 1 + 2 | | Cross LD | | | Secure Obj BAILEY | | | | |
| | E BDE OPS | Assy Area APPLE | | | Move on Routes 3 + 4 | | Cross LD | | | Secure Obj BAILEY | | Div Res | | |
| | REAR OPS | Assy Area Sy | | | | Risk as Bde Preps Attack | | Take on sy of GRANT | | | | | | |
| FIRE SP | | Prep Fwd Posn + Ammo<br>Attack Obj GRANT | | | Sp C Bde Attack | | Attack RAG fire SEAD | | | Attack RAG<br>SEAD | | | | |
| AIR DEFENCE | | Protect Assy Area<br>Protect C Bde Mov | | | Protect Bde Movs<br>Cover PL SODA | | | Mov with Lead Bde | | Cover PL GIN<br>Protect BRAVO Assy Area<br>Sp BRAVO Attack on STEWART | | | | |
| ENGINEER SP | | Route Sy | | Clear Routes 1 - 4 | | | Sp to D and E Bdes | | | Maint on BRAVO MSR<br>BRAVO Passage of Lines | | | Mob sp to Corp Tps | |
| CSS | | Refurb Div | | | Refuel D + E Bdes<br>Refurb C Bde | | | | | Resup Bdes on Obj BAILEY | | refuel BRAVO Tps | | |
| COMD | | | FWD HQ with C Bde<br>SU Moves | | | Main to GRANT<br>FWD with E Bde | | | SU Moves | | MAIN HQ BAILEY<br>FWD to BRAVO MAIN | | | |
| REMARKS | | | | | | | | | | Sp to BRAVO op | | | | |

# META

- **M**odel for **E**ngagemen**T** **A**nalysis
- AI algorithms requirements for plan evaluation model
  - Fast
  - Robust
    - No logic loopholes
    - Evaluate nonsense order sets
      - AI considers bad solutions
      - Need good measure of fitness
- META Simple
  - Representing ONLY the essential elements of the full problem
  - Simple and Robust algorithms
  - Quick and cheap (3 months, 2 man team)



Speed (time per day) : 10 seconds

Scenario Time: 09:05:00 11/12/2013

Side German

10/12/2013 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00 11/12/2013 00:00 01:00 02:00 03:00

100st Bde HQ: Normal Move to Bramley at 15:45:00 — Move — Pending

101 Bat: Defend Move to... — Move — Pending

102 Bat: Attack Move to Boxgrove at... — Move — Pending

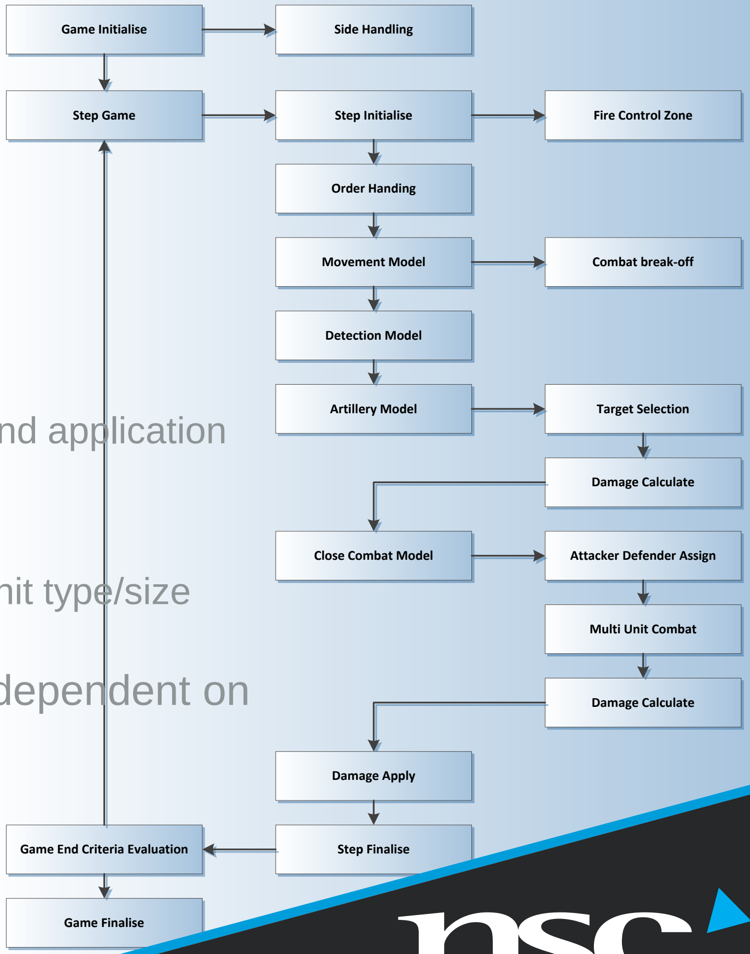
103 Bat: Retreat... — Move Pendi; Attack Move to Guildford Station at... — Move — Pending

A Bat 100 Bde: Indirect Fire at 13:45:00 — IndirectFire — Pending; I... — InPi; Indirect Fire at... — IndirectFire — Pending

nsc
training • simulation • consultancy

# META

- Aggregated land model
    - Brigade level (SimBrig)
    - Algorithms at an aggregated level
        - Quickest execution speed
        - Expose the fewest loop holes in algorithm logic and application
    - Combat:
        - Lanchester-like
        - BAMS-like 2-D cross matrix of attrition rates by unit type/size
            - Handles units of differing sizes/capabilities
    - Movement, combat, detection, artillery models dependent on
        - Terrain, unit types, postures, suppression
    - Arc, node movement network (SimBrig)
        - Zones of control
        - Internode visibility



Game Initialise

Side Handling

Step Game

Step Initialise

Fire Control Zone

Order Handing

Movement Model

Combat break-off

Detection Model

Artillery Model

Target Selection

Damage Calculate

Close Combat Model

Attacker Defender Assign

Multi Unit Combat

Damage Calculate

Damage Apply

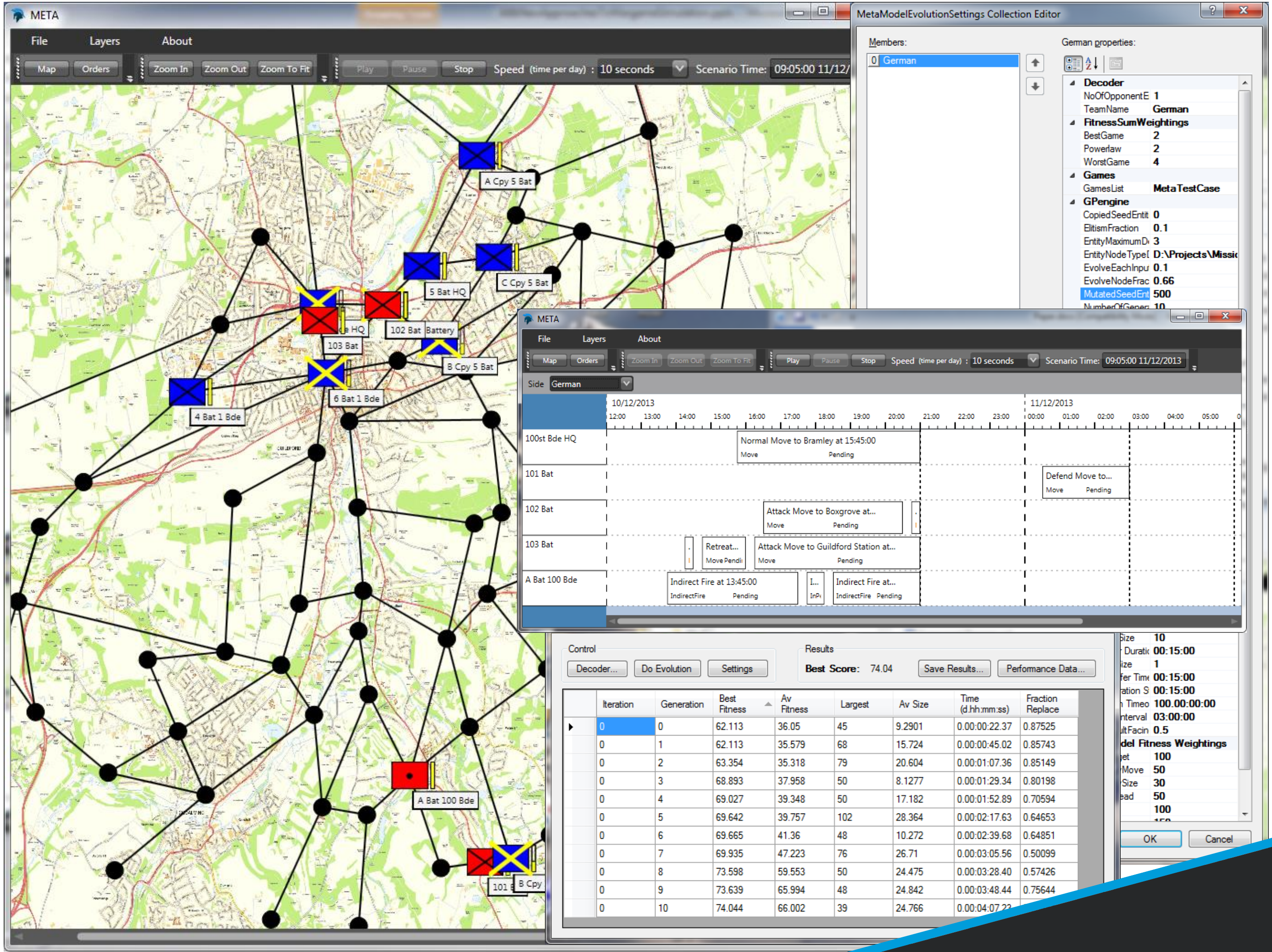
Step Finalise

Game End Criteria Evaluation

Game Finalise

# Results

- MP Demo
- META Demo



Speed (time per day) : 10 seconds
Scenario Time: 09:05:00 11/12/2013

MetaModelEvolutionSettings Collection Editor

Members:
0 German

German properties:

| | |
|---|---|
| **Decoder** | |
| NoOfOpponentE | 1 |
| TeamName | German |
| **FitnessSumWeightings** | |
| BestGame | 2 |
| Powerlaw | 2 |
| WorstGame | 4 |
| **Games** | |
| GamesList | MetaTestCase |
| **GPengine** | |
| CopiedSeedEntit | 0 |
| ElitismFraction | 0.1 |
| EntityMaximumD | 3 |
| EntityNodeType[ | D:\Projects\Missic |
| EvolveEachInpu | 0.1 |
| EvolveNodeFrac | 0.66 |
| MutatedSeedEnt | 500 |
| NumberOfGener | 10 |
| Size | 10 |
| Duratic | 00:15:00 |
| ize | 1 |
| fer Time | 00:15:00 |
| ration S | 00:15:00 |
| Timeo | 100.00:00:00 |
| nterval | 03:00:00 |
| ltFacin | 0.5 |
| **del Fitness Weightings** | |
| et | 100 |
| Move | 50 |
| Size | 30 |
| ead | 50 |
| | 100 |

Side German

10/12/2013 · 11/12/2013
12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00 00:00 01:00 02:00 03:00 04:00 05:00

| | |
|---|---|
| 100st Bde HQ | Normal Move to Bramley at 15:45:00 — Move, Pending |
| 101 Bat | Defend Move to... — Move, Pending |
| 102 Bat | Attack Move to Boxgrove at... — Move, Pending |
| 103 Bat | Retreat... — Move Pendi<br>Attack Move to Guildford Station at... — Move, Pending |
| A Bat 100 Bde | Indirect Fire at 13:45:00 — IndirectFire, Pending<br>I... — InP<br>Indirect Fire at... — IndirectFire, Pending |

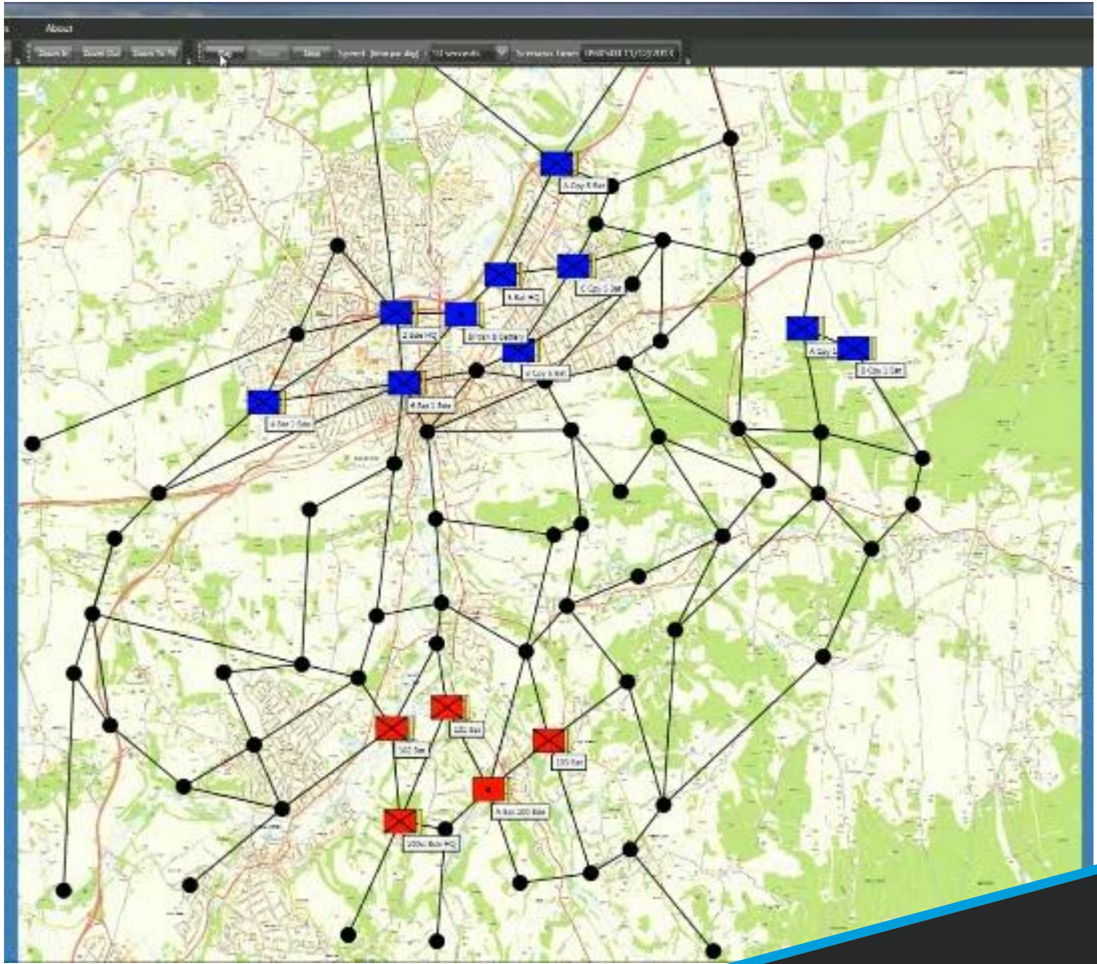
Control: Decoder... | Do Evolution | Settings

Results: **Best Score:** 74.04 | Save Results... | Performance Data...

| Iteration | Generation | Best Fitness | Av Fitness | Largest | Av Size | Time (d.hh:mm:ss) | Fraction Replace |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 62.113 | 36.05 | 45 | 9.2901 | 0.00:00:22.37 | 0.87525 |
| 0 | 1 | 62.113 | 35.579 | 68 | 15.724 | 0.00:00:45.02 | 0.85743 |
| 0 | 2 | 63.354 | 35.318 | 79 | 20.604 | 0.00:01:07.36 | 0.85149 |
| 0 | 3 | 68.893 | 37.958 | 50 | 8.1277 | 0.00:01:29.34 | 0.80198 |
| 0 | 4 | 69.027 | 39.348 | 50 | 17.182 | 0.00:01:52.89 | 0.70594 |
| 0 | 5 | 69.642 | 39.757 | 102 | 28.364 | 0.00:02:17.63 | 0.64653 |
| 0 | 6 | 69.665 | 41.36 | 48 | 10.272 | 0.00:02:39.68 | 0.64851 |
| 0 | 7 | 69.935 | 47.223 | 76 | 26.71 | 0.00:03:05.56 | 0.50099 |
| 0 | 8 | 73.598 | 59.553 | 50 | 24.475 | 0.00:03:28.40 | 0.57426 |
| 0 | 9 | 73.639 | 65.994 | 48 | 24.842 | 0.00:03:48.44 | 0.75644 |
| 0 | 10 | 74.044 | 66.002 | 39 | 24.766 | 0.00:04:07.23 | |

nsc
training • simulation • consultancy

# META Demo



# Conclusions

- “Simplicity is the ultimate sophistication”
  - Leonardo da Vinci
- AI Algorithms
  - Generic architecture – Plug and Play
    - Simple application to different problems
- Formulate the solution: Military-like syntax
  - AI algorithms efficiently generate plans for tactical problems
    - resemble human-like decision making
- Meta model - AI generates plans against a reduced problem set
  - Representing essential elements of the full problem.
  - Simple, Fast, Robust
  - Overcomes limitations of AI techniques

nsc
training • simulation • consultancy

# Dstl Conclusions

- Mission planner will allow
  - Greater range of potential solution space to be examined
  - More reactive Red allowing more robust testing of plans
  - Rapid generation of variations, examining changes in
    - Force Structure
    - Constraints
  - Improved testing of complex models

nsc

training • simulation • consultancy