The Digital Ludeme Project:

Modelling the Evolution of Traditional Games

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Game AI Working Group Seminar

CNRS, l'Université Paris Dauphine, 1 October 2018

European Research Council

Established by the European Commission

Overview

Digital Ludeme Project

- Five-year research project
- European Research Council (ERC) Consolidator Grant (€2m)
- April 2018 – 2023

Host

- Games and AI Group
- Department of Knowledge Engineering (DKE)
- Maastricht University, Netherlands

Team

- Five researchers:
  - PI
  - 3 x RA
  - 1 x PhD

Project

What It Is

- Computational study:
  - World's traditional games
  - Recorded human history

Digital Ludeme Project

Objectives

1. ***Model***: Full range of traditional games in a single playable database
2. ***Reconstruct***: Missing knowledge about games more accurately
3. ***Map***: Spread of games and assoc. mathematical ideas through history

Aim

- Improve our understanding of ancient games using modern AI

Motivation

Games and Culture

- All human cultures play games
- Cultural heritage:
  - *Music, poetry, art, games, …*

Comparative Cultural Analysis

- Best (1976):

  "Nothing is more persistent than the games of a people"

Evidence

- Games leave archaeological evidence:
  - *Boards, pieces, etc.*
- Very rarely rule sets

Problem

Knowledge Gap

- Huge gaps in our knowledge of ancient/early games

Recorded History

- Rule sets rarely written down
- Passed on by oral tradition

Modern Understanding

- Based on modern reconstructions:
  - historical/cultural analysis
  - ***not*** mathematical analysis
- Unreliable!

Examples…

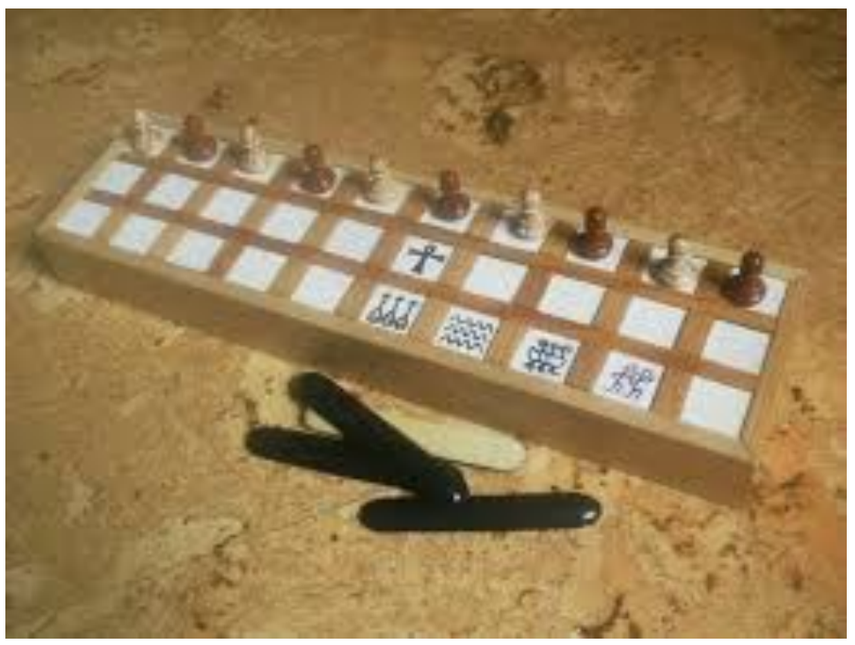
Lack of Information

Senet

- Egypt, c.3100BC
- Many sets found, no rules
- Hieroglyphic hints:
  e.g. starting position
- Is it a game?

Special Symbols

- Murray (1952) : *Entry points?*
- Kendall (1978): *Exit points?*



Loss of Information

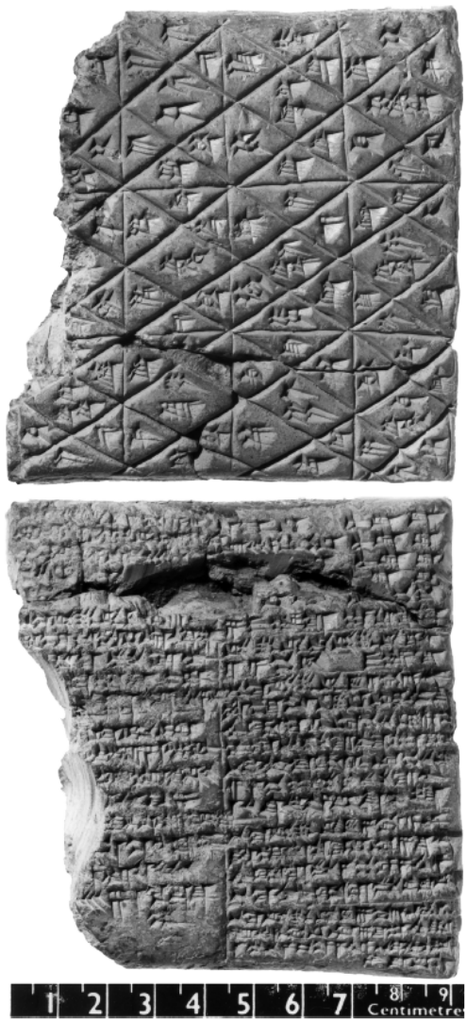
Royal Game of Ur

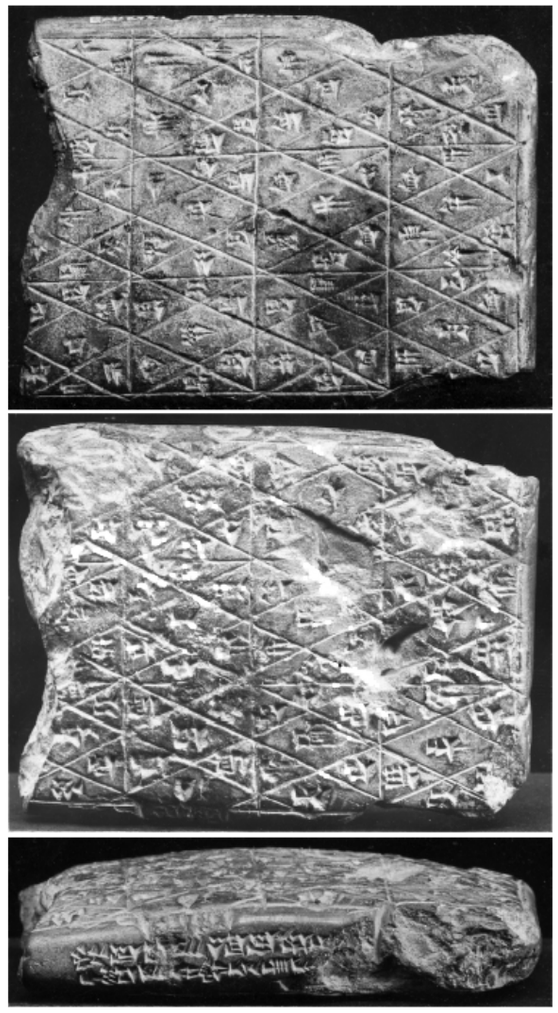
- Mesopotamia, 2600BC

- Tablets dated 177BC:
  - *B.M.*: One of 130,000
  - *Paris*: Destroyed 1940s

- Oldest recorded rules
- Interpreted by Finkel (1990)
- Themselves interpretations 2,500 years later

- Game played for 4,500 years?
- Longer than most civilisations or religions





Translation Errors

Hnefatafl

- Scandiavia, c.400BC
- No rules recorded

Linnaeus (1732)

- Saw Tablut played
- Recorded in travel diary in Latin

Smith (1811)

- Translated "…likewise the king…" as "…except the king…"
- Biased rule set, unlikely to be accurate

Murray (1913)

- Published biased rules, became *de facto*
- Corrected ever since

Lack of Analysis

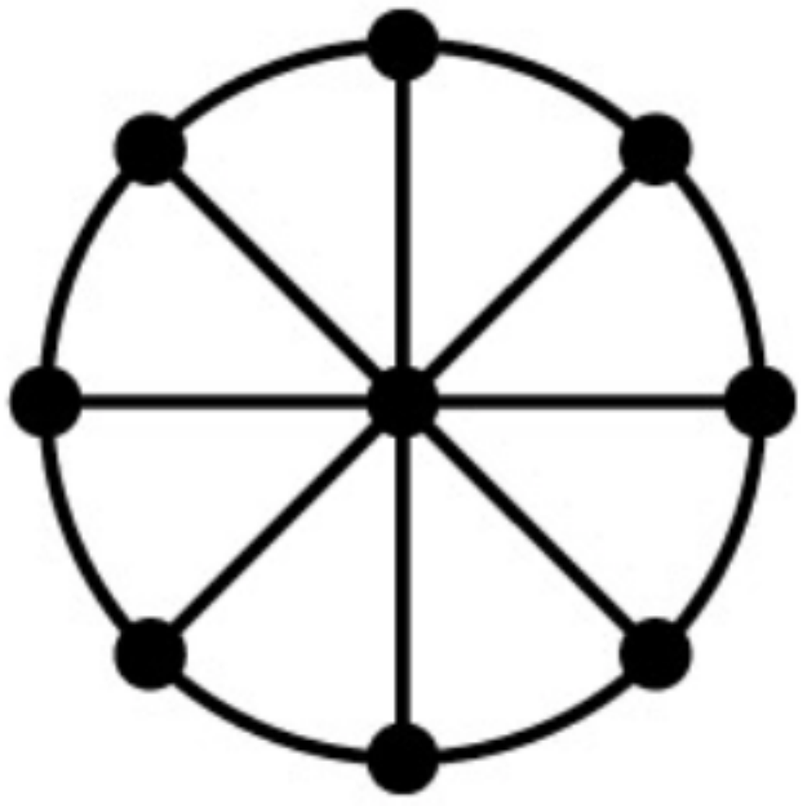
Assos (Turkey)

- Game board ~300BC
- Assumed Small Merels

Does Small Merels Work?

- Blünheim rules (1918)
- Became *de facto*
- Mathematical analysis (2014):
  - Prone to cycles!

- Is this a plausible rule set?
- Do cycles ruin the game?



Transcription Errors

Mu Torere

- Maori, New Zealand, 18thC
- Opening rule:

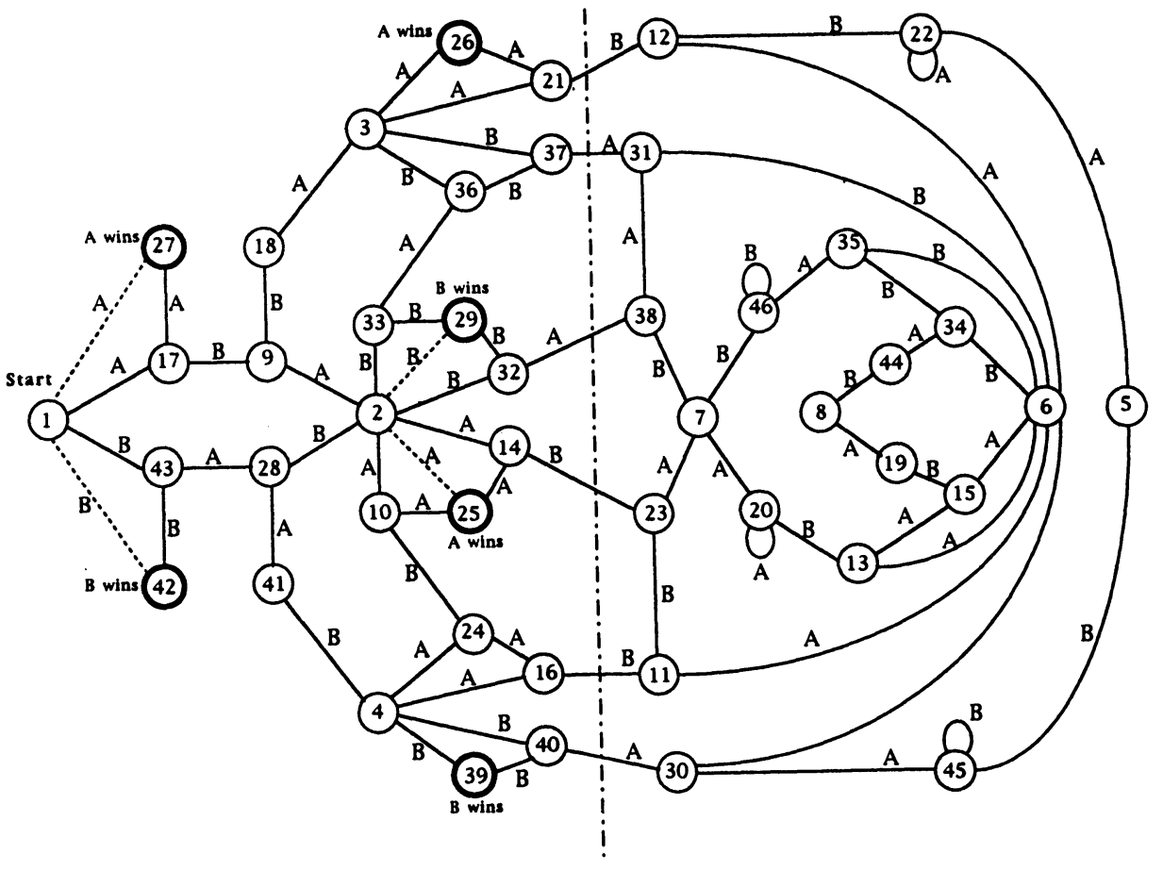
The first piece moved must be adjacent to an enemy piece.

Marcia Ascher (1987)

- Two accounts neglect this rule
- Game ends after one move!

Straffin (1995)

- Mathematical solution
- 46 states



Loss of Evidence

Hounds and Jackals

- Egypt, ~2000BC

Azerbaijan Carving

- Azerbaijan, ~2000BC
- Game? Calendar? Art?
- Evidence of cultural contact?

Walter Crist (US Anthropologist)

- 2016 visit:
  - Site analysis
  - Notches for canopy
- 2017 visit:
  - Housing development

- Evidence is fragile!

Cultural Contact?

Comparitive Cultural Analysis

- Patolli (Mexico)
- Pachisi (India)

Tyler (1879)

- Evidence of early contact

Erasmus (1950)

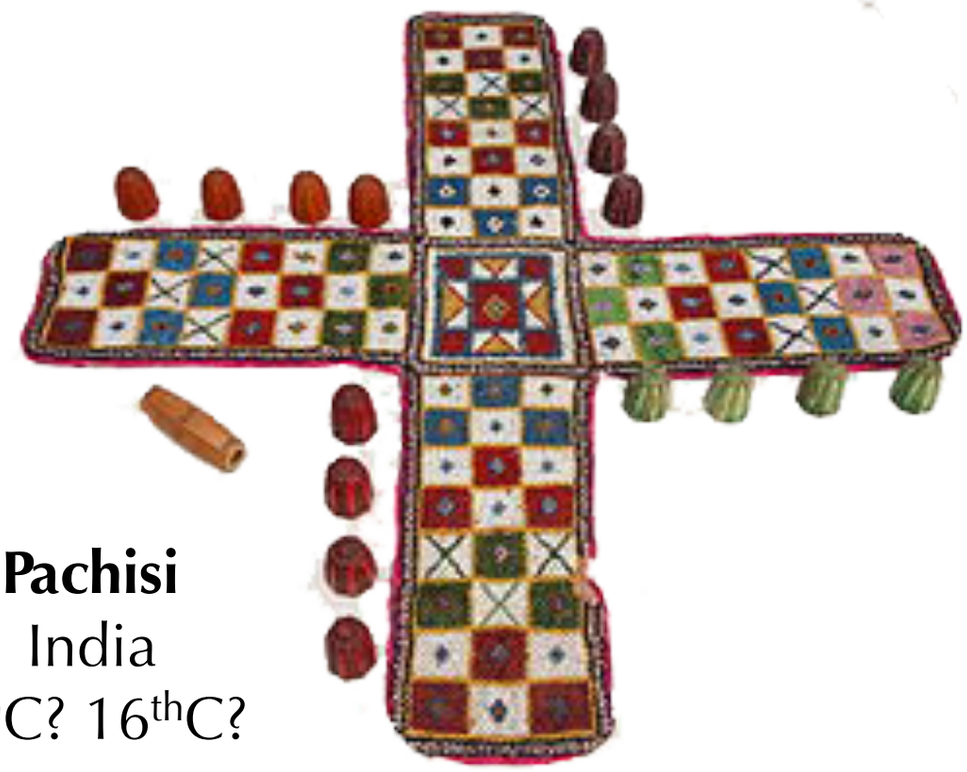
- Coincidence
- “Limitation of Possibilities”

Murray (1952)

- Coincidence unlikely

- How to decide?

Patolli
Mexico
c.200BC



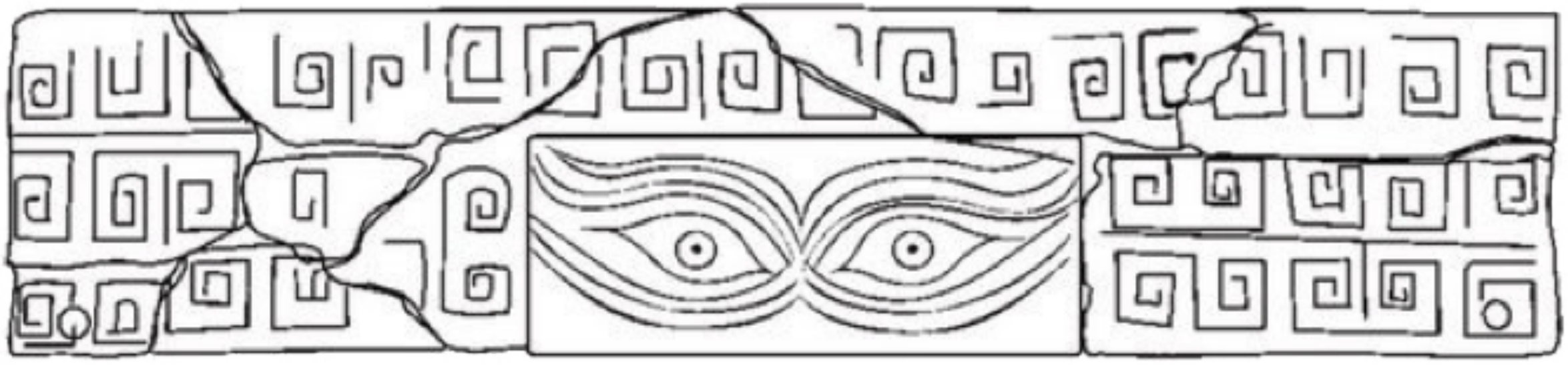
Pachisi
India
6thC? 16thC?

Partial Evidence

Qingzhou City (China)

- Tomb dated to 300BC
- Board + 14-sided die
- Assumed to be Liubo

- Is it even a game?
  - Should be able to determine



Partial Evidence

Poprad (Slovakia)

- Tomb dated to 375AD
- Germanic chieftain

What Game?

- No precedent in Europe
- Board:
  - 17x15/16 grid (not Go!)
- Pieces:
  - 2 x Colours
  - 1 or 2 x Sizes?

Reconstruction

- Ulrich Schadler (2018): *"An impossible task"*
- Currently no tools to help

Research Problem

Problem

- Knowledge of ancient games is unreliable:
  - Based on (flawed) reconstructions
- No digital tools to help historians

Solution

- Game AI mature research field
- Not applied to ancient games (yet)

Approach

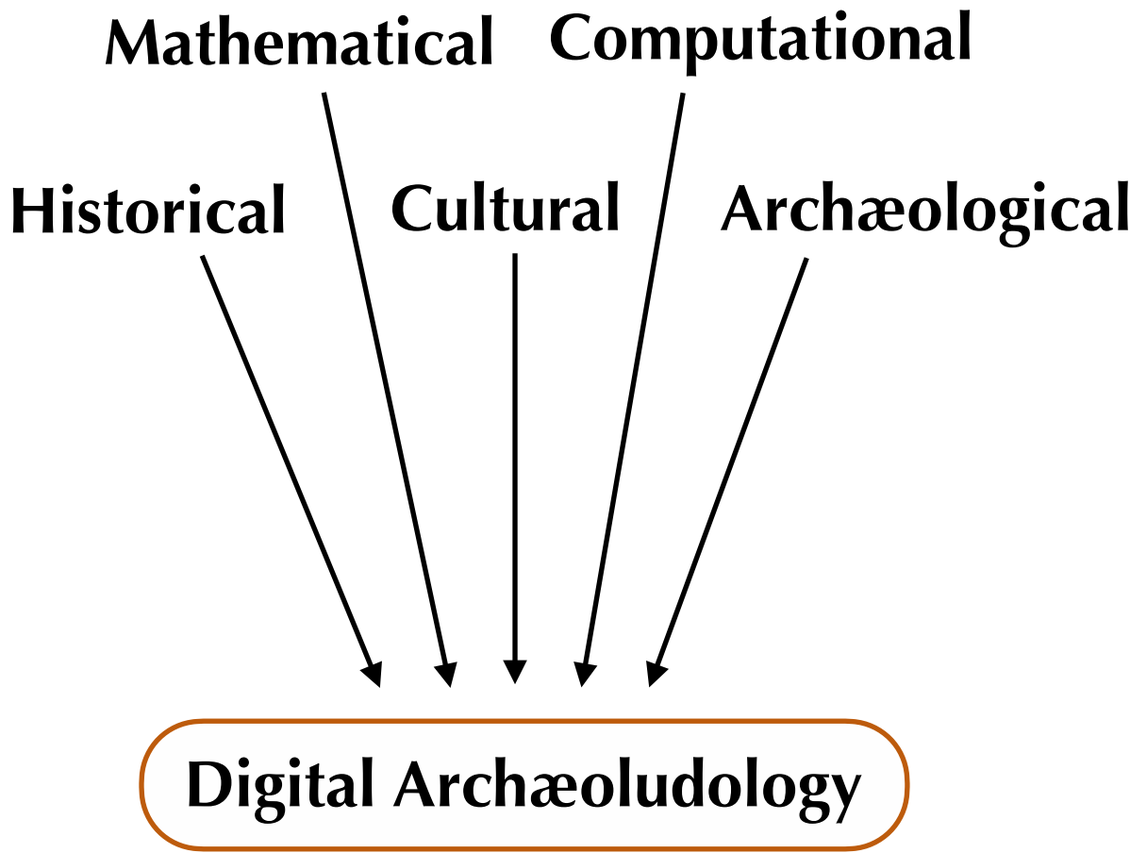
- Model games digitally
- Maximise reconstructions for:
  - Mathematical **quality** (as games)
  - Historical **authenticity** (as cultural artefacts)

Digital Archæoludology

Digital Archæoludogy

- New field of research
- Many research strands
- Single unified approach

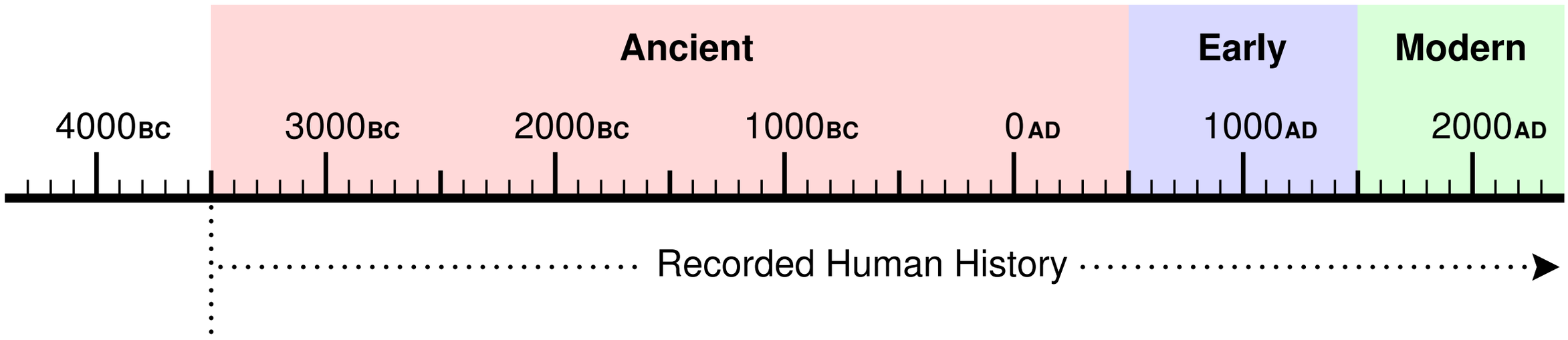
- Modern comput. techniques:
  - Analysis and reconstruction
  - Incomplete descriptions



Scope

Traditional Games of Strategy

- *Traditional*: No known inventor or proprietary owner
- *Strategy*: Reward strategic planning + mental skill
  e.g. board games, tile, card, dice, math. games, etc.



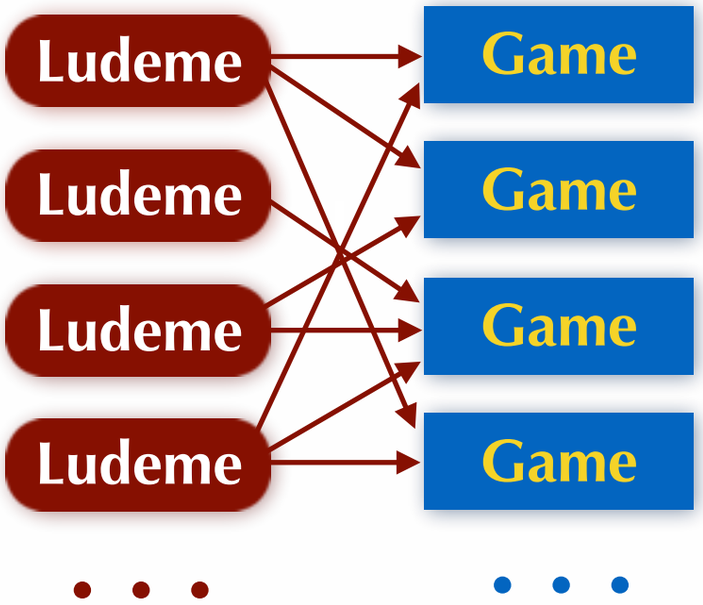
Range

- ~3500BC – ~1900AD
- 1,000 most influential games (plus variants)
- Further back, less we know

Methodology

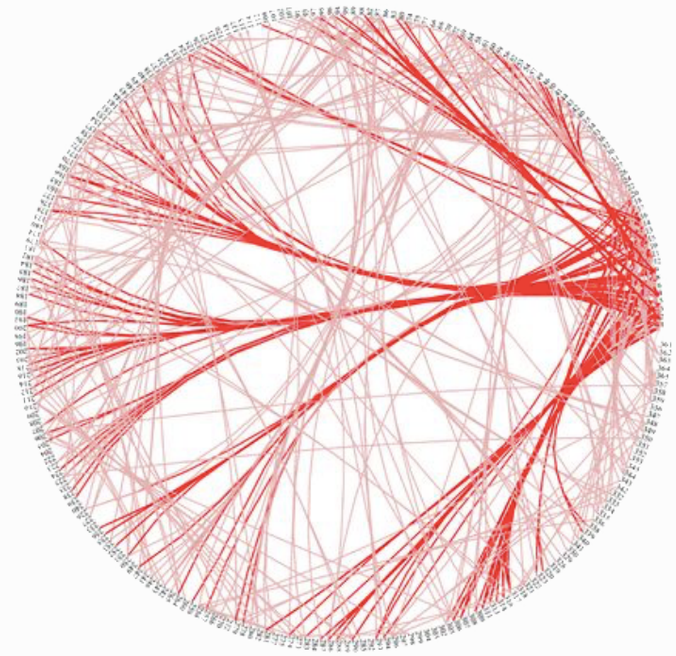
1. Model

LUDII Game System



2. Reconstruct

Phylogenetics



3. Map

Cultural Mapping

Methodology

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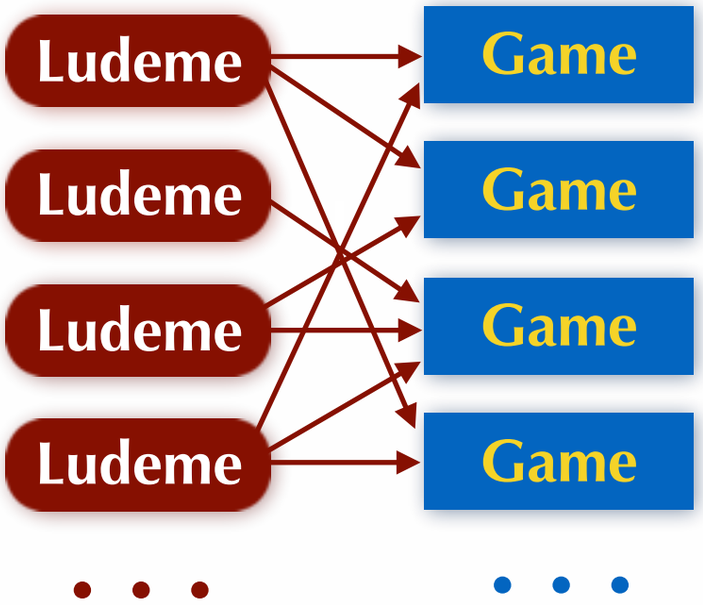

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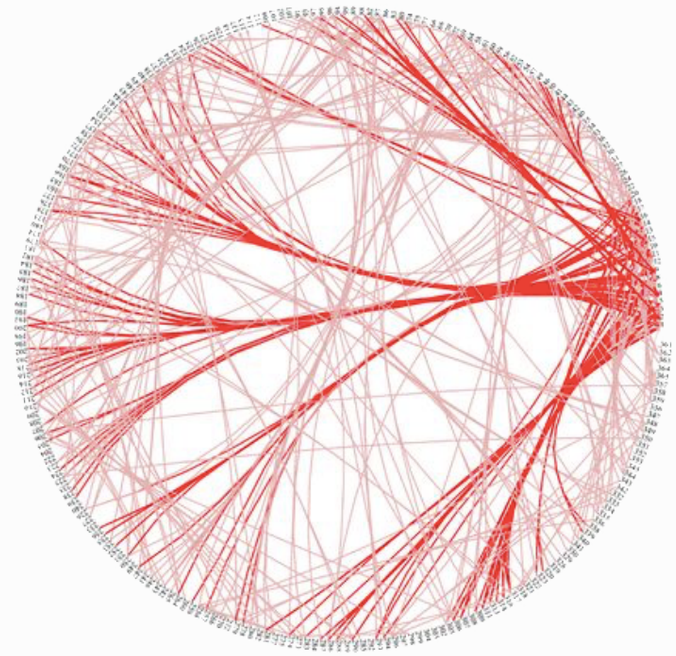

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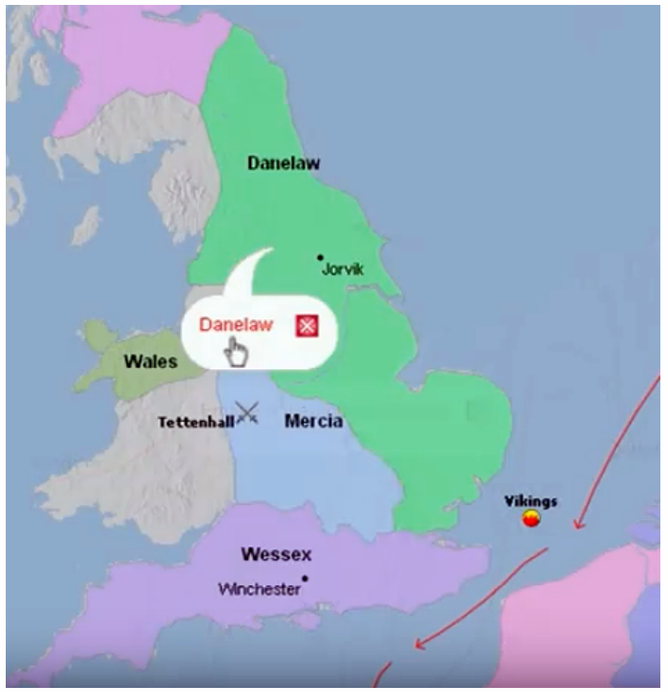

Ludemes

Ludemes

- "Game memes"
- Units of game-related information
- Building blocks (DNA) of games
- PhD thesis (2009)

```
(game "Tic-Tac-Toe"
  (players White Black)
  (board (square 3))
  (play
    (add
      (piece Own)
      (board Empty)
    )
  )
  (end (win All (line 3 Own Any)))
)
```

Practical Benefits

- Compact, comprehensible
- Editable, evolvable
- Human-readable
- Efficient

Allows full range of games

Theoretical Benefits

- Encapsulate concepts
- **Label concepts**

Game Description Languages

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```

Stanford GDL

```
(role white) (role black)
(init (cell 1 1 b)) (init (cell 1 2 b)) (init (cell 1 3 b))
(init (cell 2 1 b)) (init (cell 2 2 b)) (init (cell 2 3 b))
(init (cell 3 1 b)) (init (cell 3 2 b)) (init (cell 3 3 b))
(init (control white))
(<= (legal ?w (mark ?x ?y)) (true (cell ?x ?y b))
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(<= (legal white noop) (true (control black)))
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(<= (next (cell ?m ?n x)) (does white (mark ?m ?n))
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(<= (next (cell ?m ?n ?w)) (true (cell ?m ?n ?w))
    (distinct ?w b))
(<= (next (cell ?m ?n b)) (does ?w (mark ?j ?k))
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```

Stanford GDL

- Standard for GGP
- Academic use
- Verbose
- Inefficient
- No encapsulation

Game Description Languages

```
(game "Tic-Tac-Toe"
  (players White Black)
  (board (square 5))
  (play
    (add
      (piece Own)
      (board Empty)
    )
  )
  (end (win All (line 3 Own Any)))
)
```

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```

Game Description Languages

```
(game "Tic-Tac-Toe"
  (players White Black)
  (board (hexHex 5))
  (play
    (add
      (piece Own)
      (board Empty)
    )
  )
  (end (win All (line 4 Own Any)))
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    )
  )
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```

LUDII

LUDII General Game System

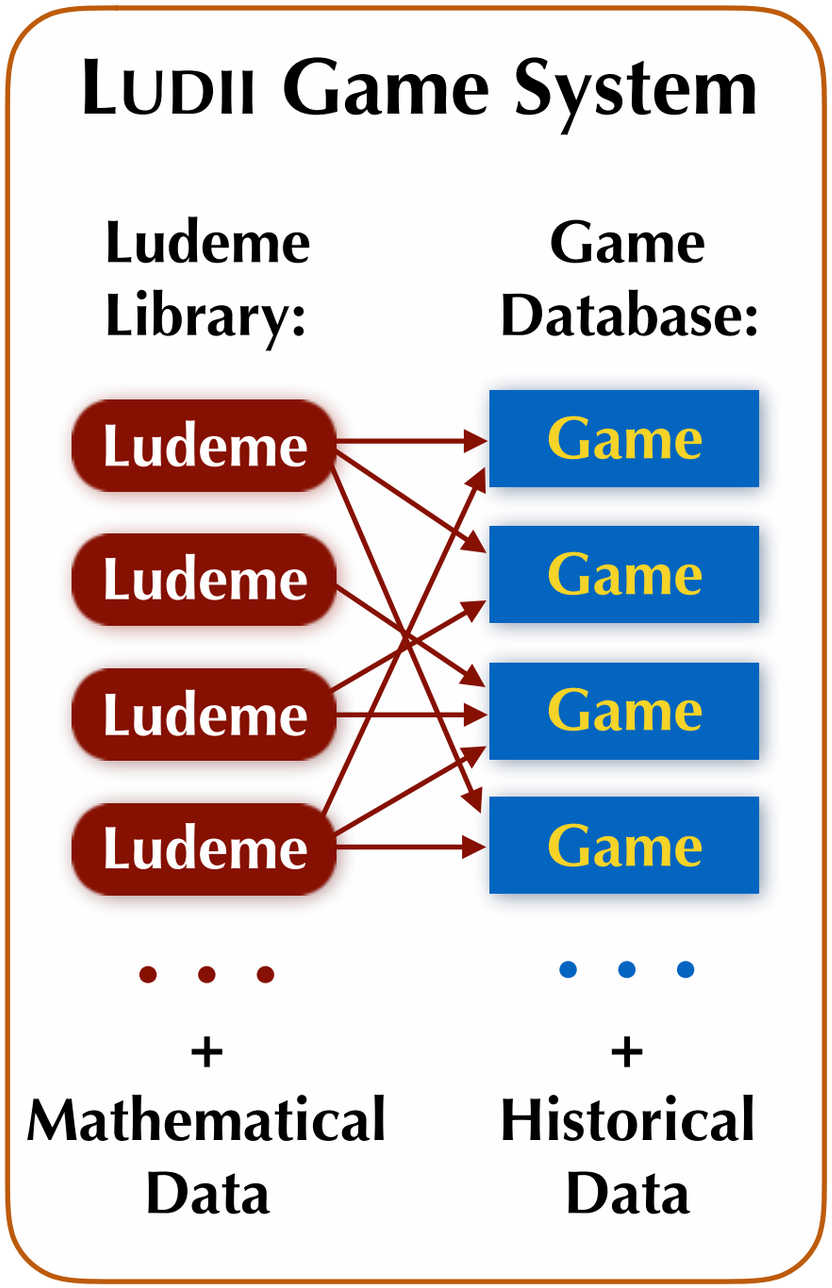
- Based on earlier LUDI system (2009)
- Play, evaluate, reconstruct
- Full range of traditional games

Ludeme Library

- Each ludeme is a Java class (*.java)
- Meaningful name
- Tagged with math. keywords

Game Database

- Each game is a *s-expression* (*.txt):
  - Ludeme tree
  - Compiles to executable Java bytecode
- Tagged with relevant historical data: *where, when, …*



Class Grammar

LUDII Class Grammar

- EBNF-style grammar
- Derived automatically from ludeme code base
- Each class generates a rule, e.g.

```
public Board(final Basis basis, @Opt final Modify[] modify) {...}
```

generates:

```
<board> ::= (board <basis> [{<modify>}])
```

Benefits

- Code sync'd to grammar
- Hides implementation
- Full access to functionality
- Extensible!

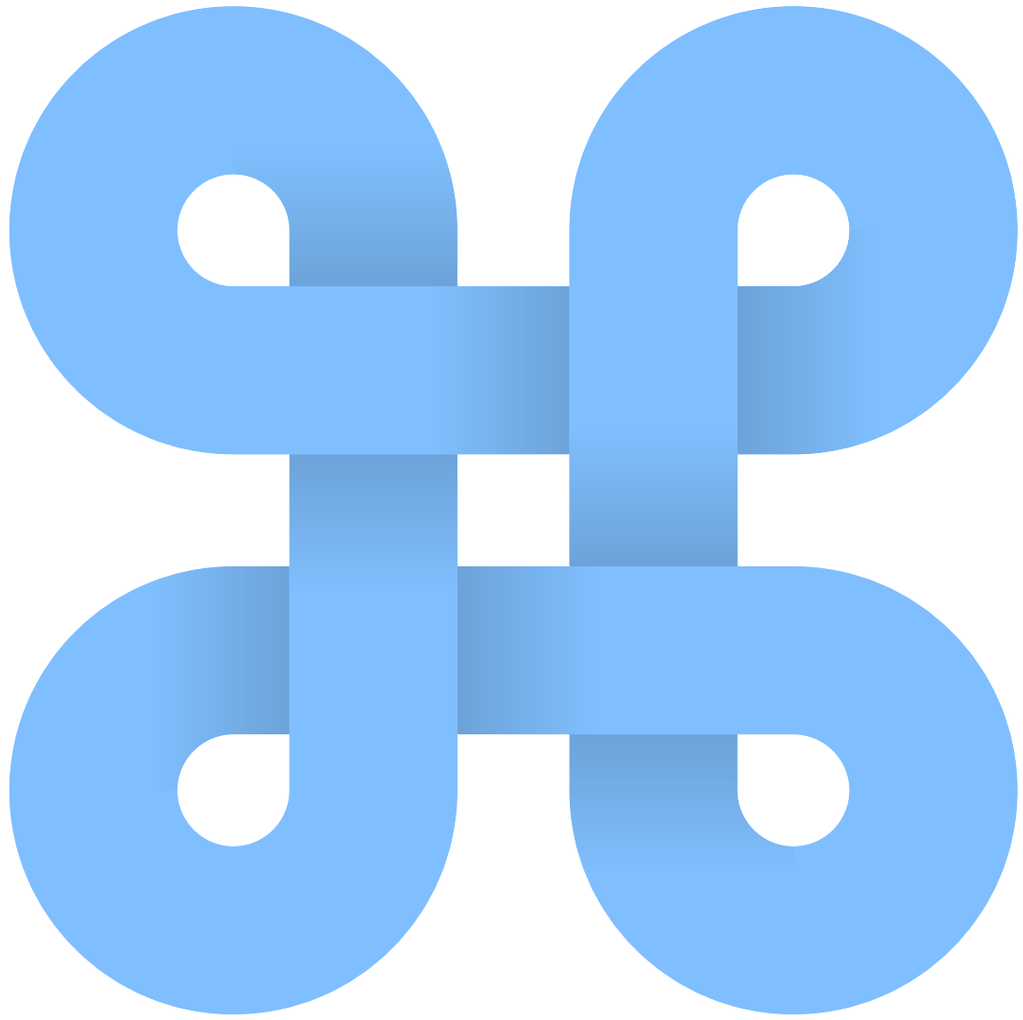
LUDII Portal

LUDII Public Portal

- Access games in the database:
  - Play AI agents
  - Play other users
  - Evaluate rule sets
  - AI tournaments

- www.ludii.games

- Release:
  - Mid-2019?



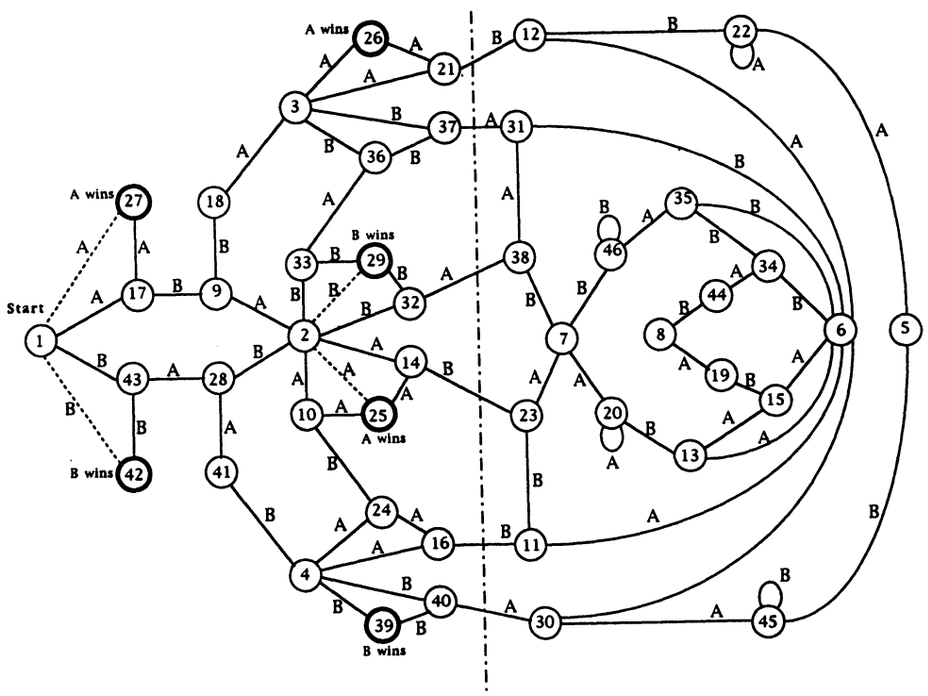
Game Evaluation

Game Preferences

- Vary by culture, period, individual, etc.
- No universal indicators

Robust Flaw Detection

- Bias
- Drawishness
- Game length



Can eliminate flawed reconstructions… but is that enough?

Strategic Potential

Traditional Strategy Games

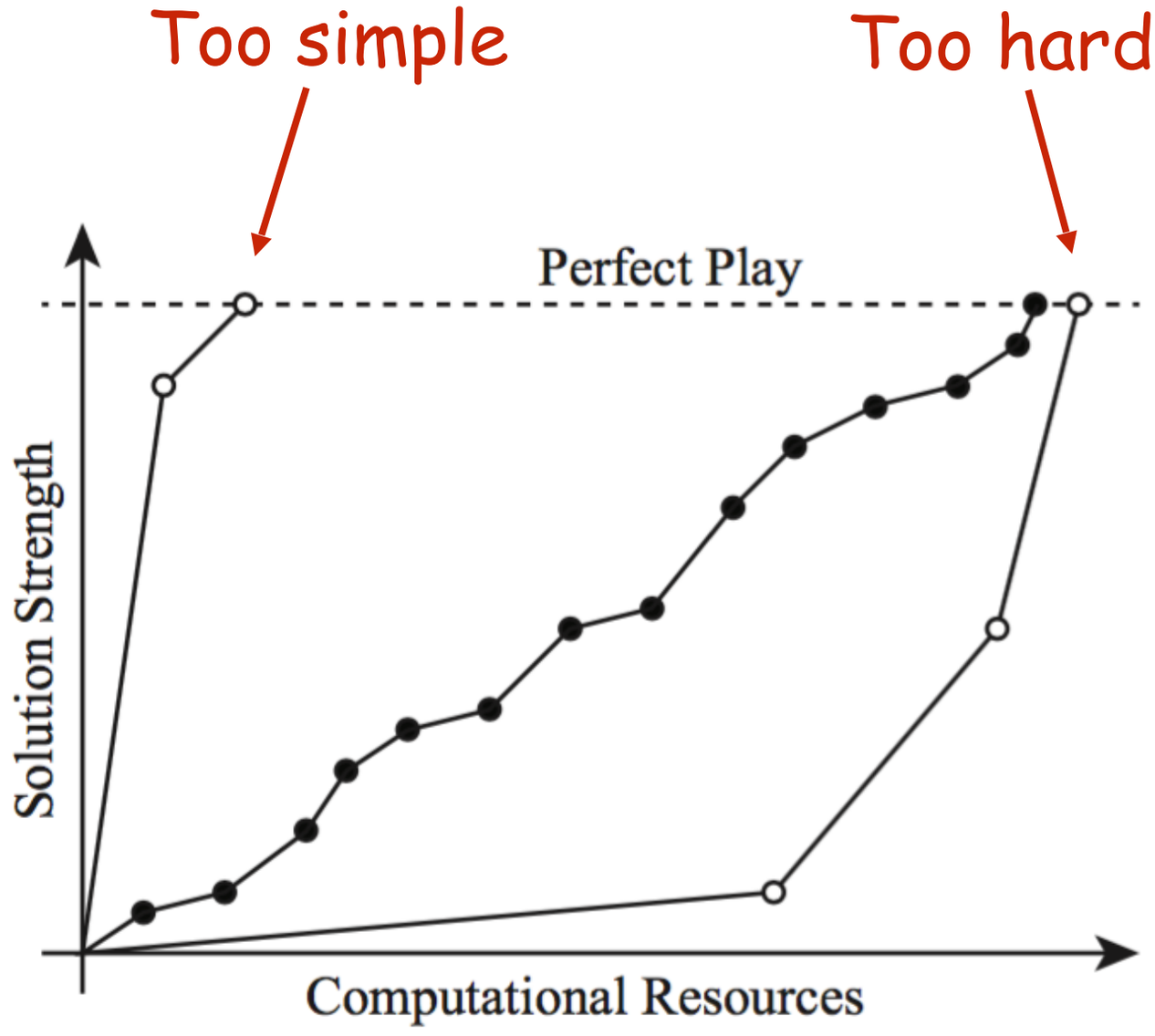
- Strategy is important

Strategy Ladder

- Lantz *et al.* (2017)
- Strategic potential

Interestingness

- Allis *et al.* (1991):
  - *"intellectual challenge neither too simple nor too hard"*



Lantz *et al.* (2017) *AAAI'17*

Plausible AI

Playing Strength

- Don't need superhuman AI… don't ***want*** superhuman AI!
- Skewed experience of games:
  e.g. Checkers drawish at championship level

Plausible AI

- Average–strong human level
- Moves that human players would plausibly make
- 50% win rate against top 50% of players?

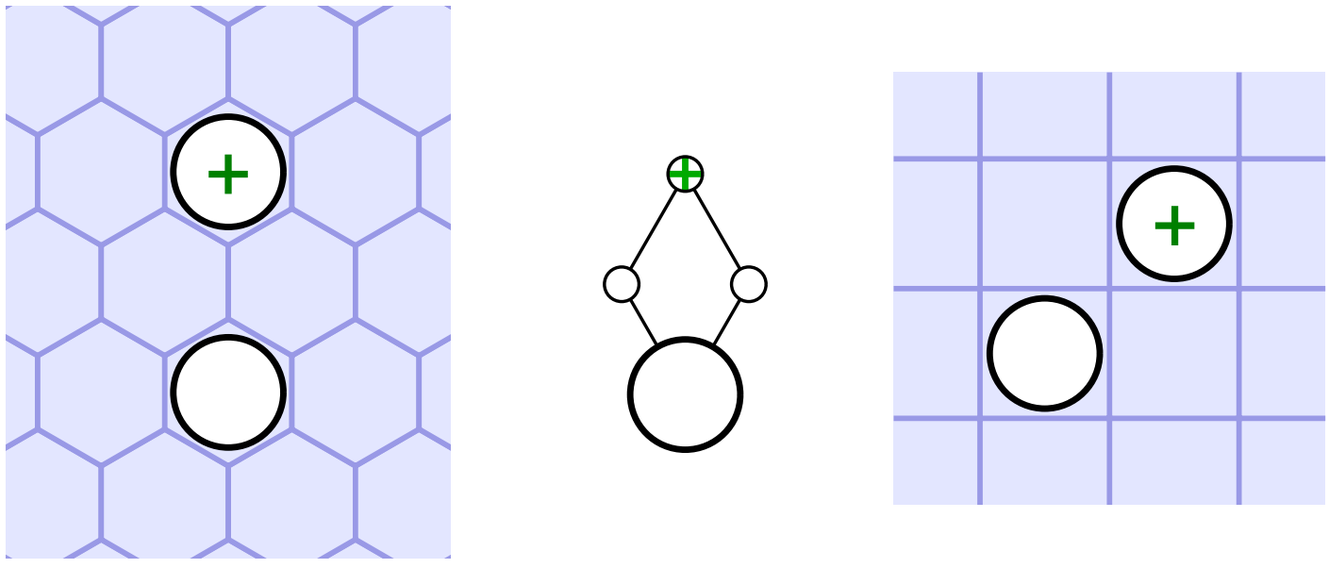
Aim

- Realistic experience of games as actually played
- Recognise strategic potential

Move Planning

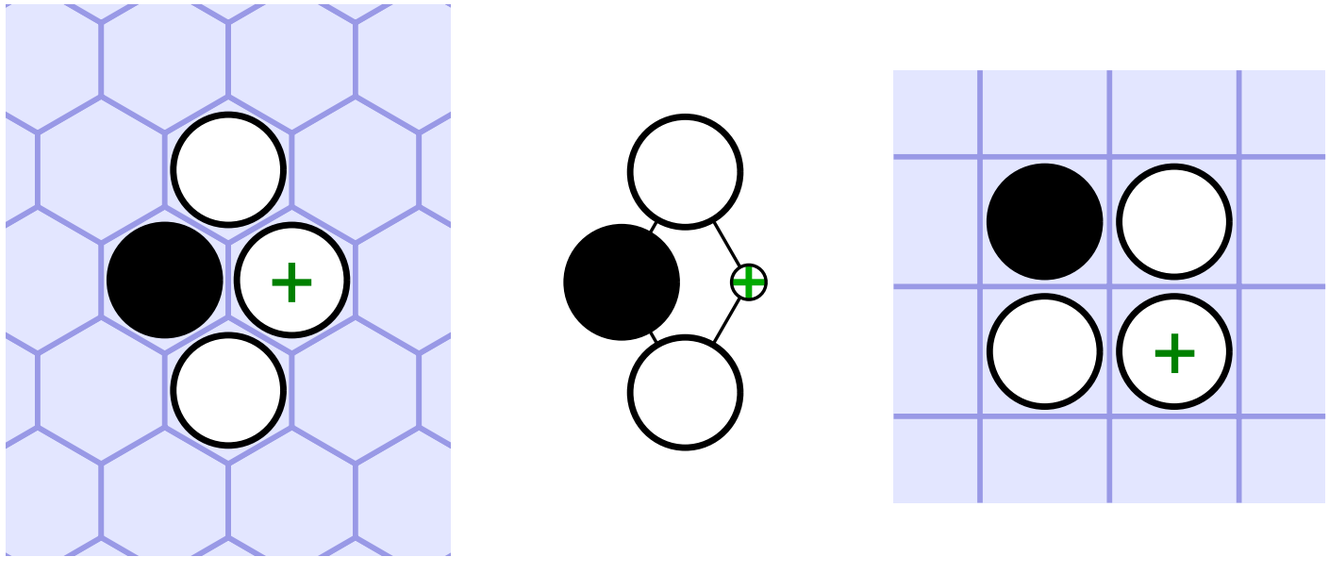
MCTS

- Good baseline
- Playouts biased by features:
  – Geometric piece patterns
- Learnt through self-play,
  e.g. Hex bridges



Geometry-Independent

- Based on graph adjacency
- Transfer to other bases
- Succinct

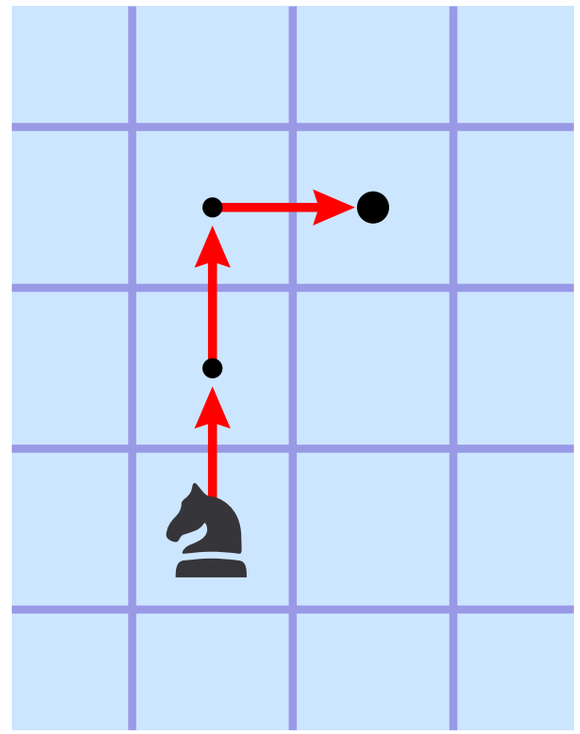


```
//   e f
//  f +
“All:rot=D:val=0.5:act={-1}:
 pat=<e{},f{0},f{-2},-{-1}>”
```

Feature Geometry

Geometry

- Relative cell locations
- Steps through adjacent cells (*turtle steps*)



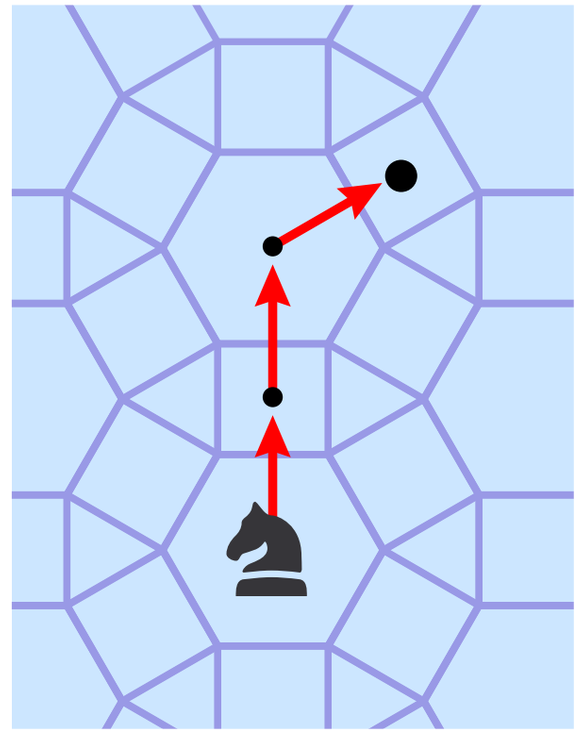
Example

- Knight move: {f, f, r, f} = {0, 0, 1}

$P_k = \{0,0,1\}$

Advantages

- Transfer between geometries/games
- Efficient
- Small memory footprint
- Human-comprehensible descriptions?

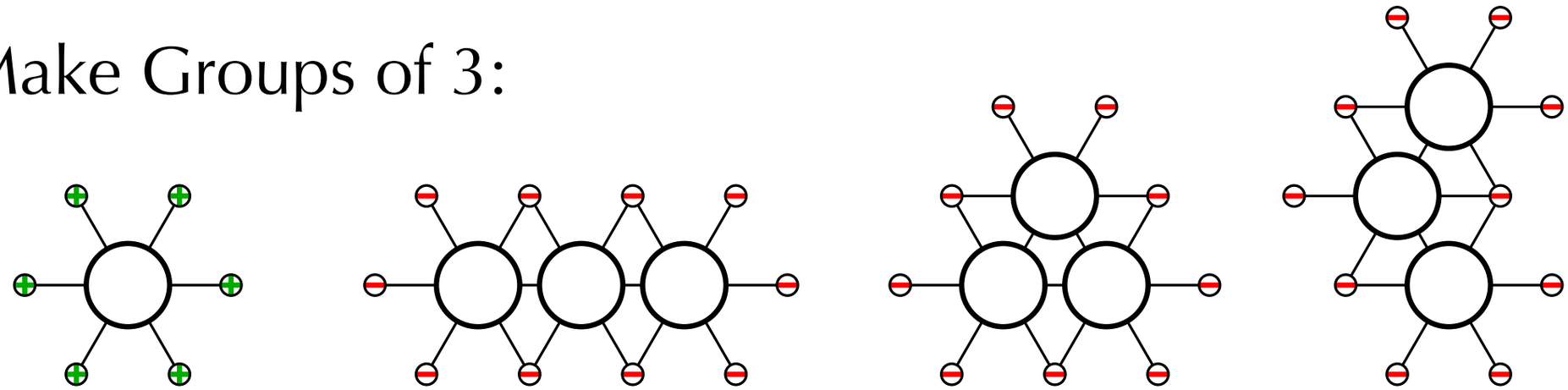


Features Encode Strategies

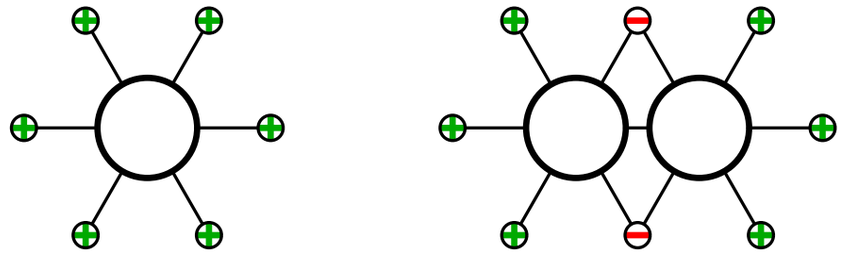
Make Lines of 4:

Avoid Lines of 3:

Make Groups of 3:



Make Long Thin Groups:



Hypothesis: *Features indicate strategic potential of game*

Why Not AlphaZero?

Resources

- AlphaZero trained on 5,000 TPUs = $25m hardware
- Weeks of supercomputer time per game

Memory

- NN memory footprint:
  - MBs per game

Need

- Not needed for “plausible AI”
- Not how games were played!
- Doesn’t reveal strategies

Practicalities

Game Count

- 1,000 source games
- Several variants each
- *Feature learning*: hundreds of feature combinations per variant
- *Optimisation*: hundreds more variants per game
- > 1 million rule sets to evaluate

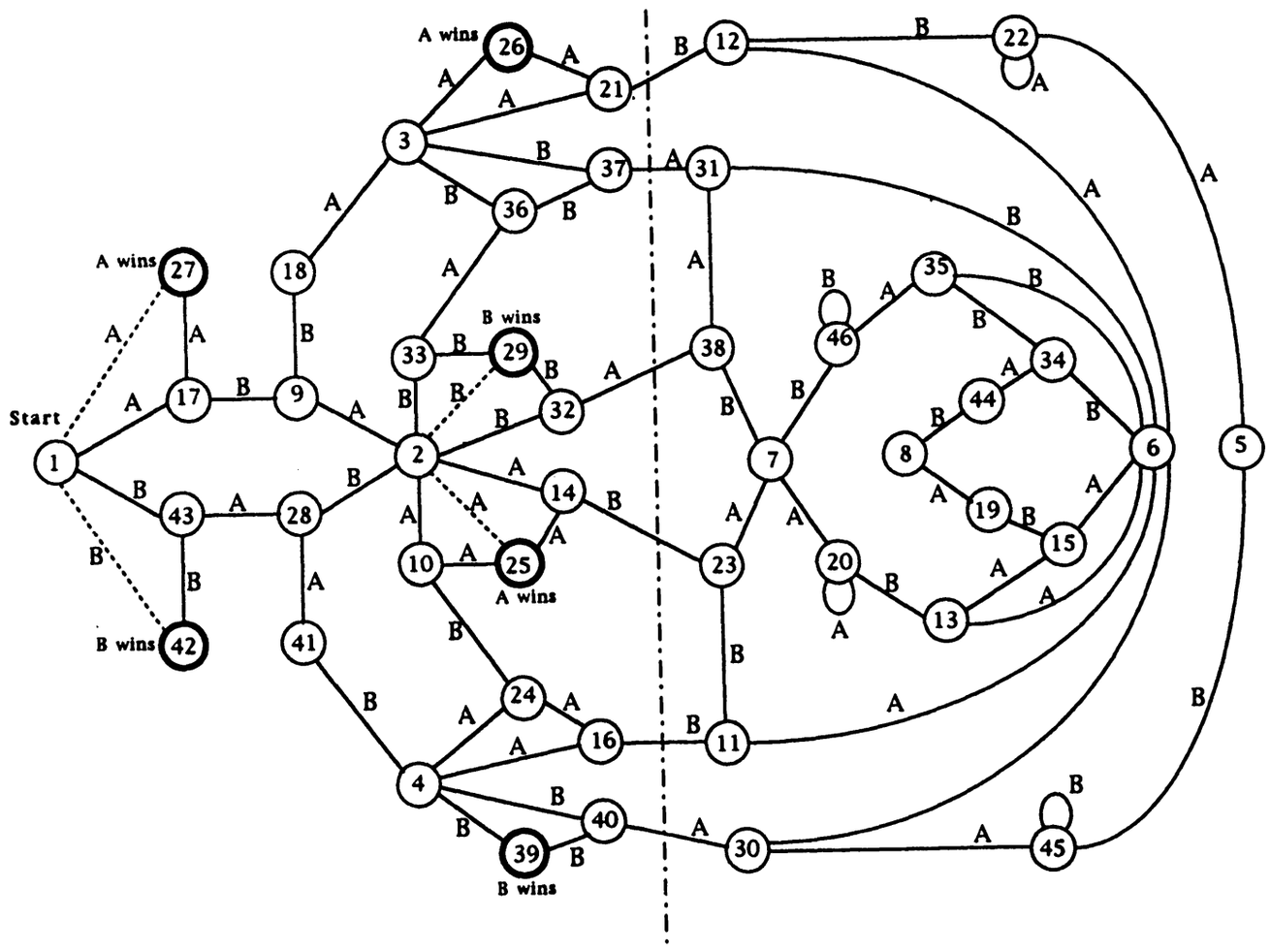
Evaluation

- Requires full playouts:
  - Parallel trials
  - 1-2 second per move = 1-2 minute per game

Range of Games

State Complexity

- Mu Torere: 46
- Go: ~1.74×10^{172}



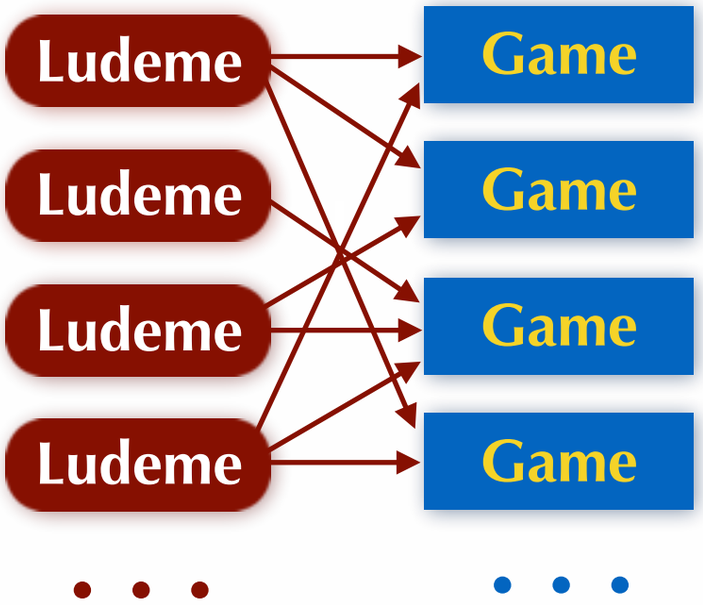
- How to compare?
  - Mu Torere effectively 0 compared to Go

- Strategic potential:
  - Large difference
  - Rather than astronomical difference

Methodology

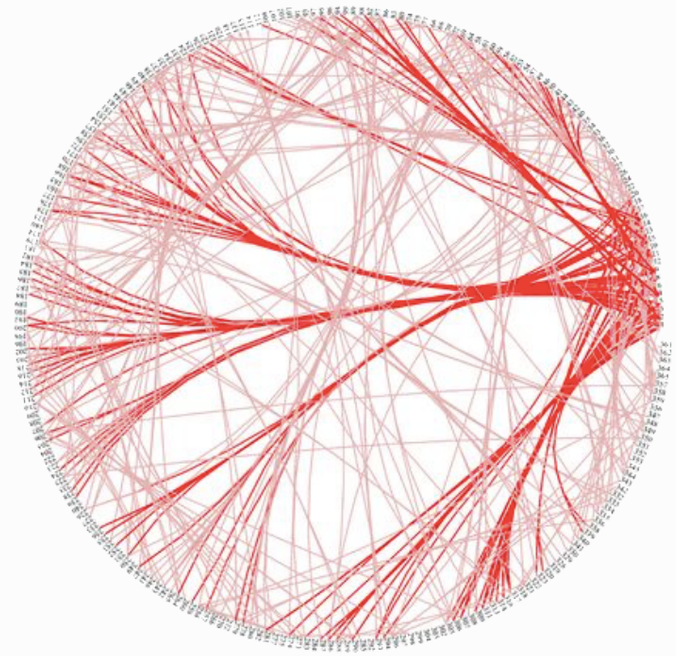
1. Model

LUDII Game System



2. Reconstruct

Phylogenetics



3. Map

Cultural Mapping

Phylogenetics

Phylogenetics

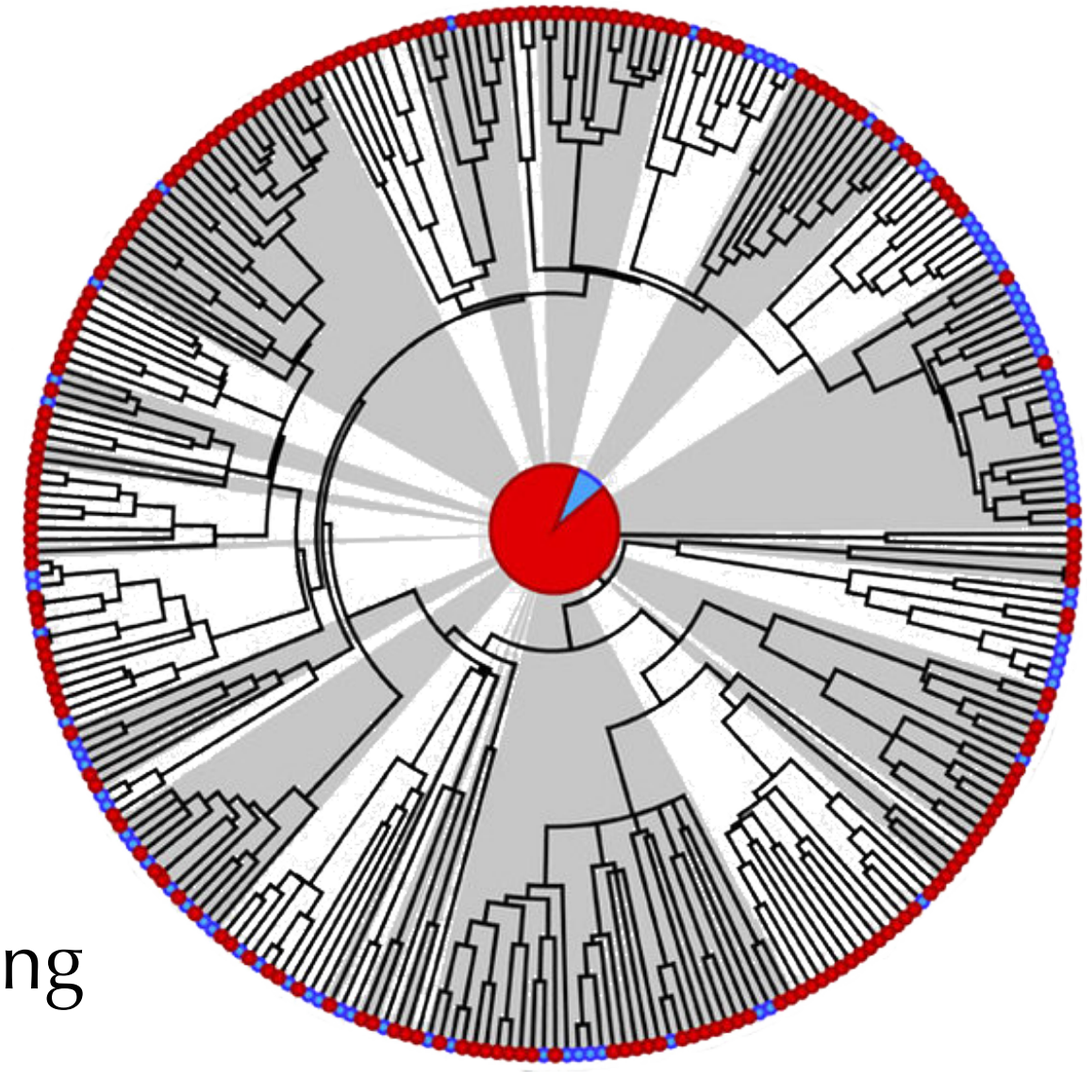
- Evolutionary history of organisms
- Family tree

Ancestral State Reconstruction

- Ancestral traits with confidence

Example

- Female song in songbirds
- 95% confidence female ancestor sang



Odom *et al.* (2014) ***Nature***

Powerful

- Can be used to reconstruct games?

Missing Links

- Induce games for which no evidence exists?

Genetics of Games

Games

- Ludemes = genotype = form
- Play = phenotype = function

Good

- Genotype/phenotype separation:
  - Needed for phylogenetic analysis
- Games highly evolvable (PhD, 2009)
- Analogies for most genetic properties

Bad

- Games combine rules arbitrarily:
  - Horizontal gene transfer (vertical assumed for phylogen. analysis)
  - No time consistency (skip generations)
- No genetic material! No genealogy

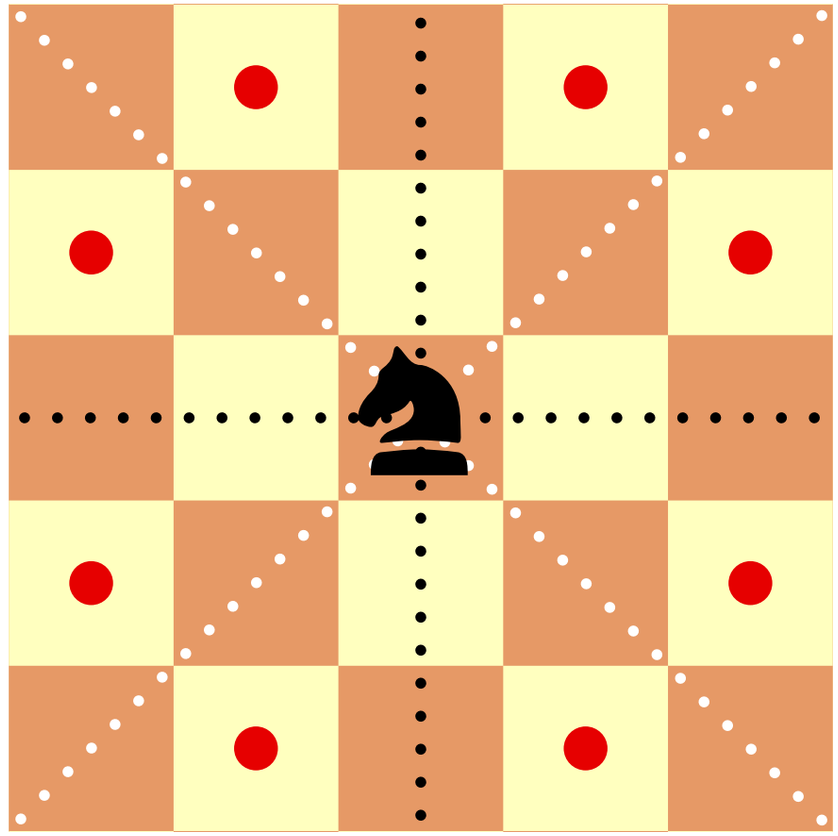
Game Distance

Genetic Distance

- Needed for phylogenetic analysis

Game Distance

- Edit distance between ludeme trees
- Weighted by importance of each ludeme



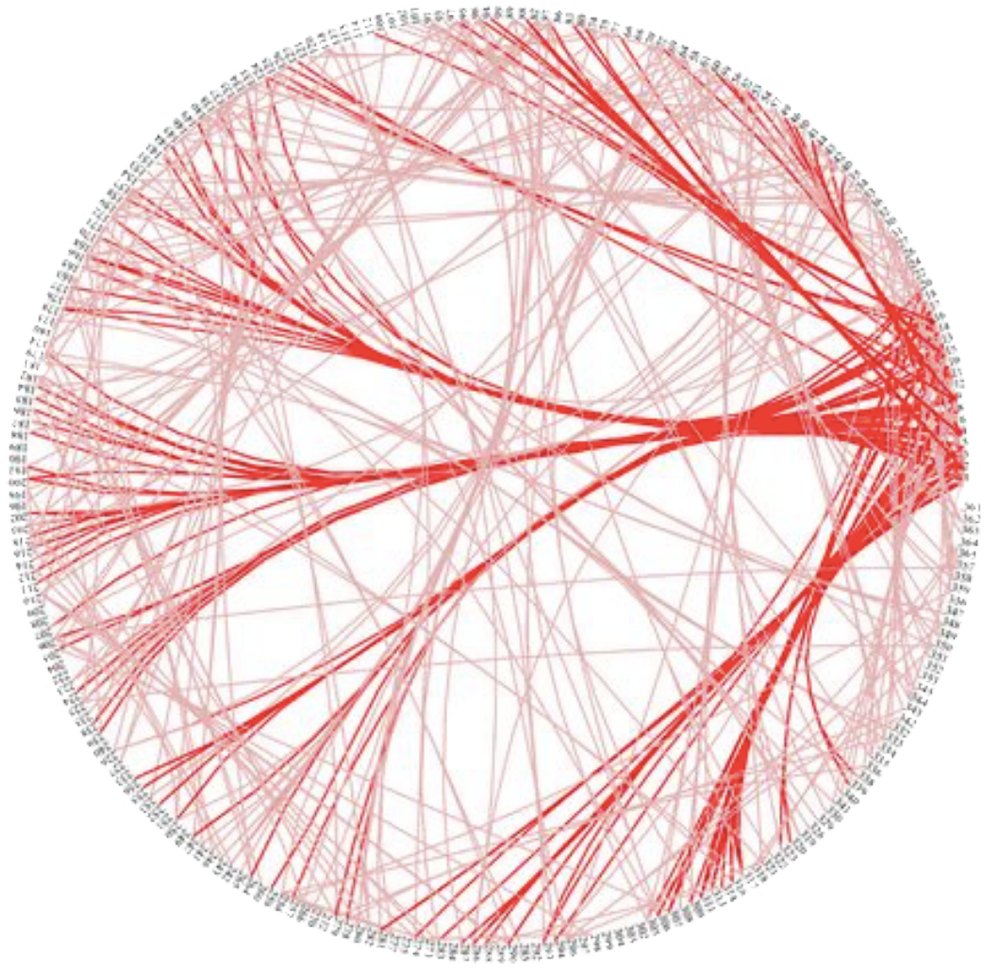
Homologies

- Different ludemes give same behaviour
- e.g. Knight move:
  - ‘L’ step
  - 3 orthogonal steps
  - Orthogonal step + diagonal step
  - Closest cell not in orthogonal or diagonal line
  - Closest non-adjacent cell of different colour, etc.

Horizontal Influence Maps

Horizontal Influence Maps

- Valverde & Sole (2015)
- Different view of relationships between data



Valverde & Sole (2015) ***JRSI***

Benefits

- Doesn't rely on vertical gene transfer

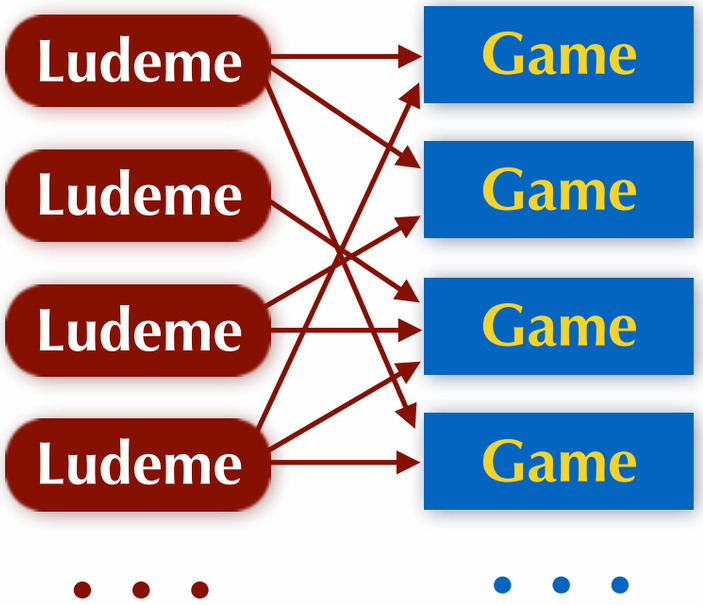
Domain

- Programming languages
- *Similar*: Mathematical domain, no genetic material
- *Dissimilar*: Tendency towards complexity

Methodology

1. Model

LUDII Game System



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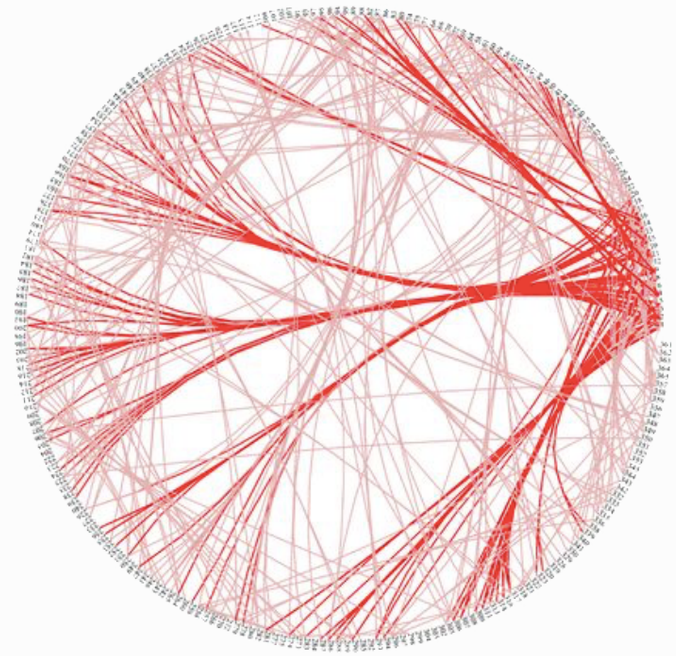


3. Map

Cultural Mapping

Cultural Mapping

Project Data

- *Ludemes*: Mathematical concepts
- *Games*: Historical data (*where, when, …*)

Mathematical Profile

- For each game, ludemes provide a *mathematical profile*

Ludemic Spread

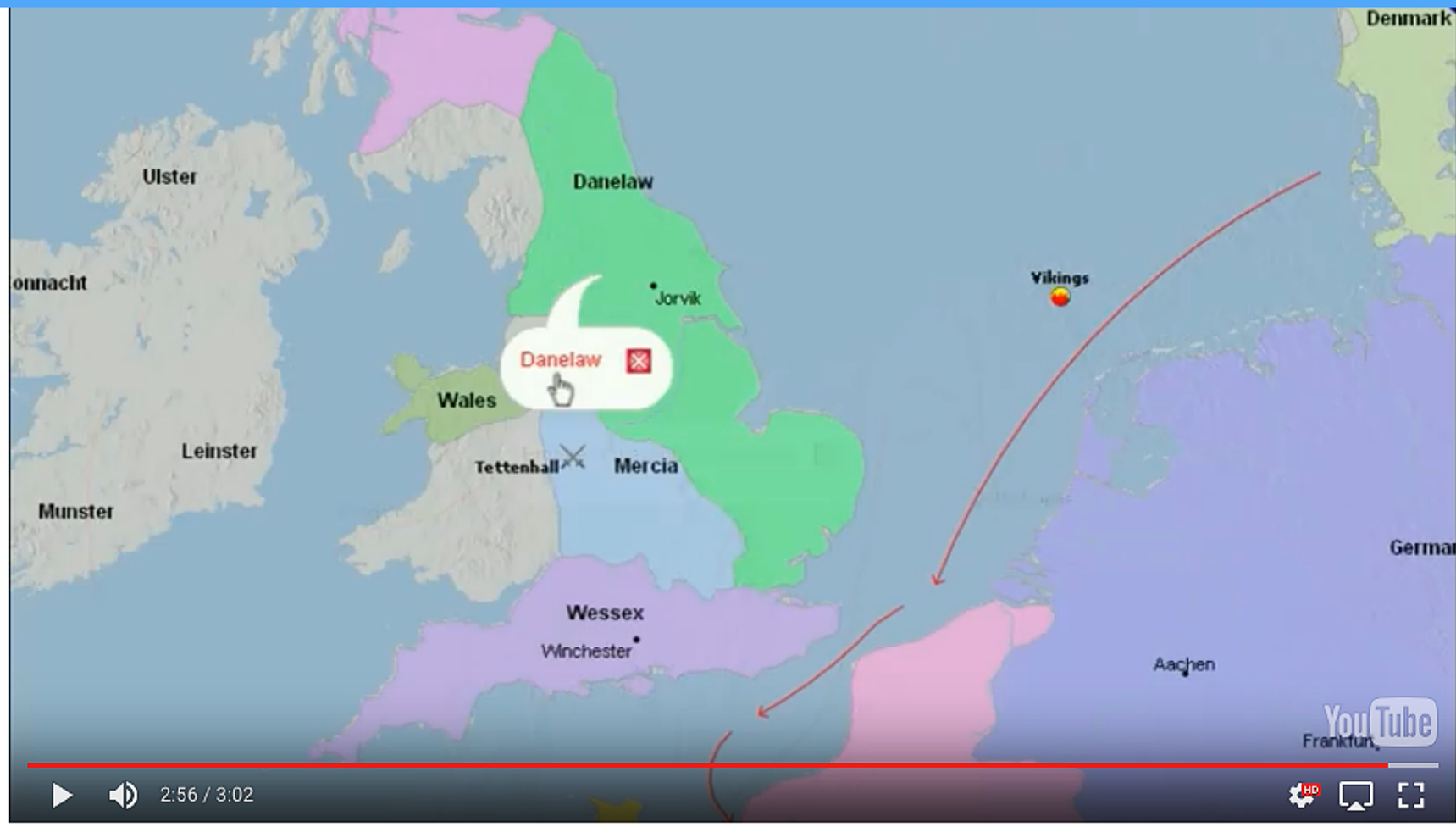
- Correlate ludemes with games
- Chart their spread

How to locate games culturally?

GeaCron

GeaCron

- Geo-temporal DB
- Yearly maps
- 3,000BC —
- 2,000 cultures



Viking route from Norway to Paris (845AD)

Services

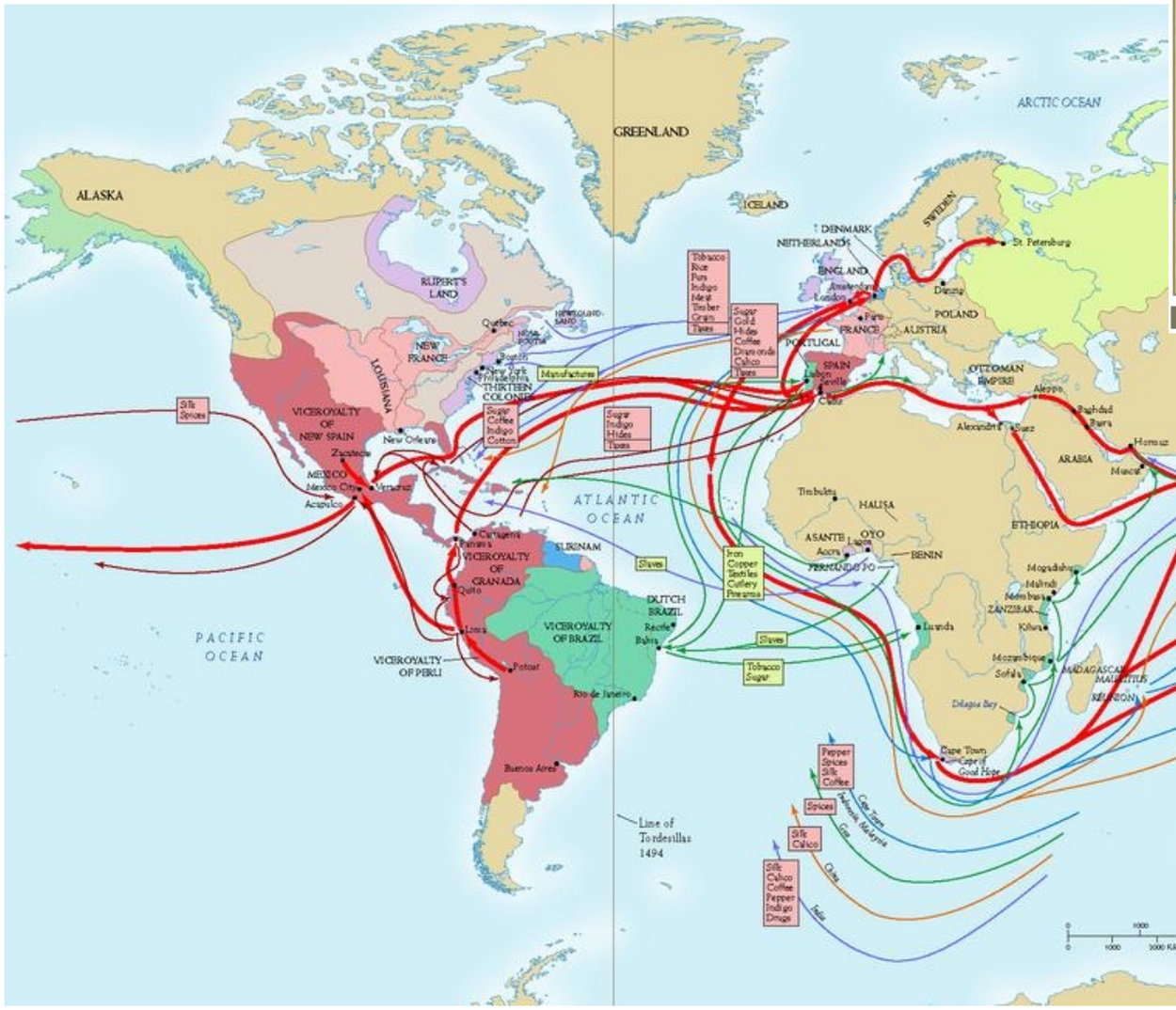
- Locate by GPS+Date:
  - Culture
  - Civilisation
  - Country/nation/state
  - Landmarks (e.g. towns)
  - Historical event

Historical profile ⇒ cultural location

Cultural Spread

Correlate Spread of Games/Ideas

- Trade routes
- Exploration routes
- Diasporas



Colonial trade routes

Map 12.1 The silk roads,

Silk Road trade routes (Fertile Crescent)

Forensic Game Reconstruction

Given

```
(board (rect 17 16))   /   (board (rect 17 15))
(players White Black)
(pieces (disc White)(disc Black))
(pieces (disc White 1)(disc White 2)(disc Black 1)(disc Black 2))
```

Find

```
(start...)   (play...)   (end...)
```

Search

- Known ludemes
- Plausible rule sets

Maximise

- Game quality: *strategic potential*
- Historical authenticity: *cultural location*

Poprad game (again)

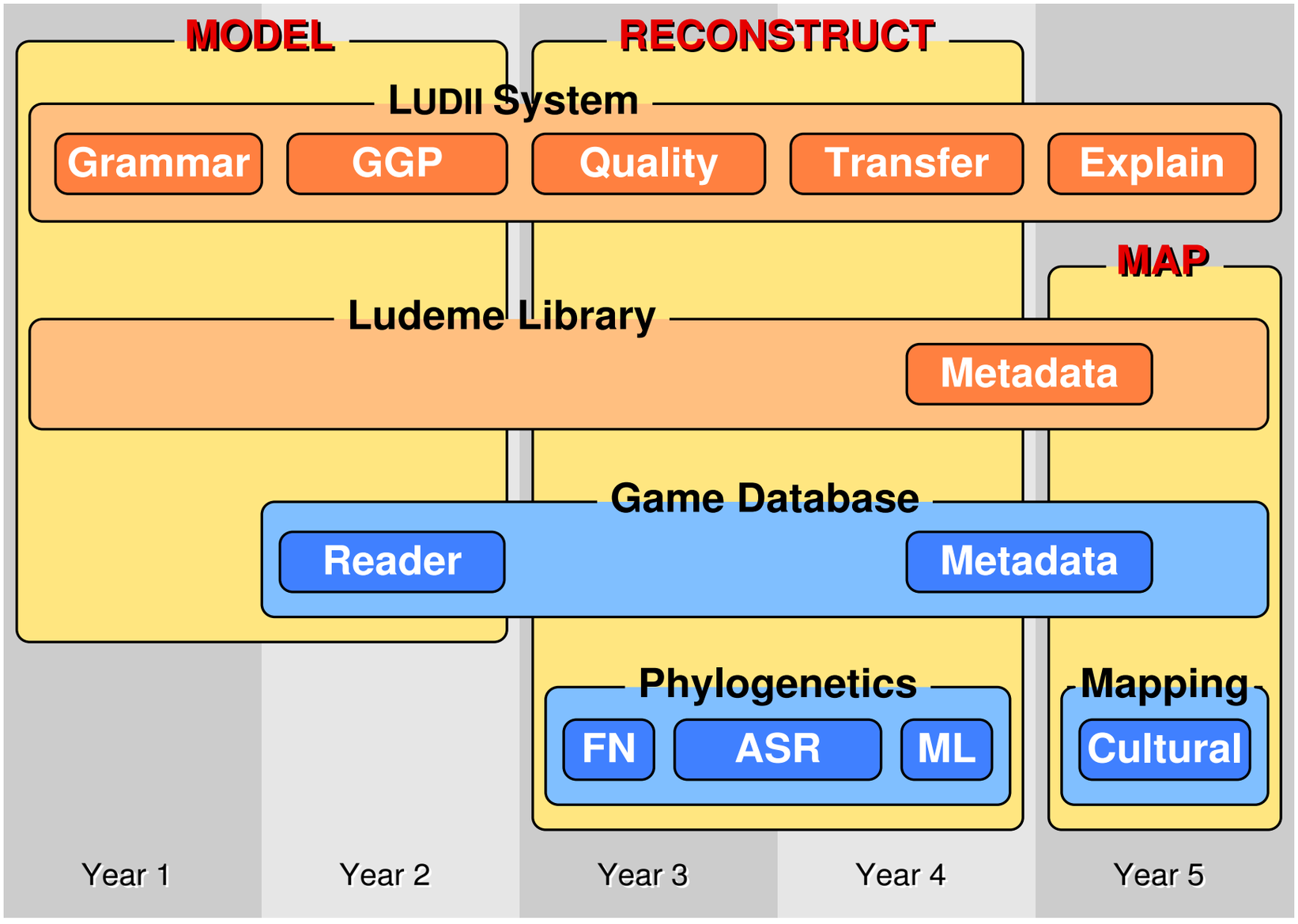
"Impossible" task ⇒ Difficult task

Workplan

PI

RA1, PhD1
(Computational)

RA2, PhD2
(Cultural)



OUTPUTS

Ludii
- GGP system
- Ludemes
- Games + Reconstructions
- Manuals
- Web site
- AI methods

Sympos. 1
- Proceedings

Sympos. 2
- Proceedings

Conference
- Proceedings

Exhibition
- Catalogue
- Interactive Maps
- Public lectures
- Artefacts
- Displays

Other
- 45+ papers
- 3 books
- 2 PhD theses
- Patents?

FN = Family Tree/Network
ASR = Ancestral State Reconstruction
ML = Missing Links

Team

Principal Investigator

- Cameron Browne

Computational

Postdoc

- Eric Piette

PhD

- Dennis Soemers

Cultural

Postdoc

- Hiring in 2019
- Historian/Anthropologist
- Advise on: *games, data, collation*

Postdoc

- Matthew Stephenson

Conclusion

Digital
Ludeme
Project

http://www.ludeme.eu

Thank You!

Go
China, 548BC
(Japanese players)

Cultural Context

Birrguu Matya

- Australian Aboriginal, 19thC?
- Traditional game?

Problems

- No precedent
- At odds with cultural philosophy
- "Invented tradition" (Hobsbawm, 2000)

Meggitt (1958)

- German missionary
- Afghan camel herders

- How to identify such outliers?