Feasibility of Capturing Crafts-based Knowledge in an AI System, for Future Autonomous Precision-surface Manufacturing

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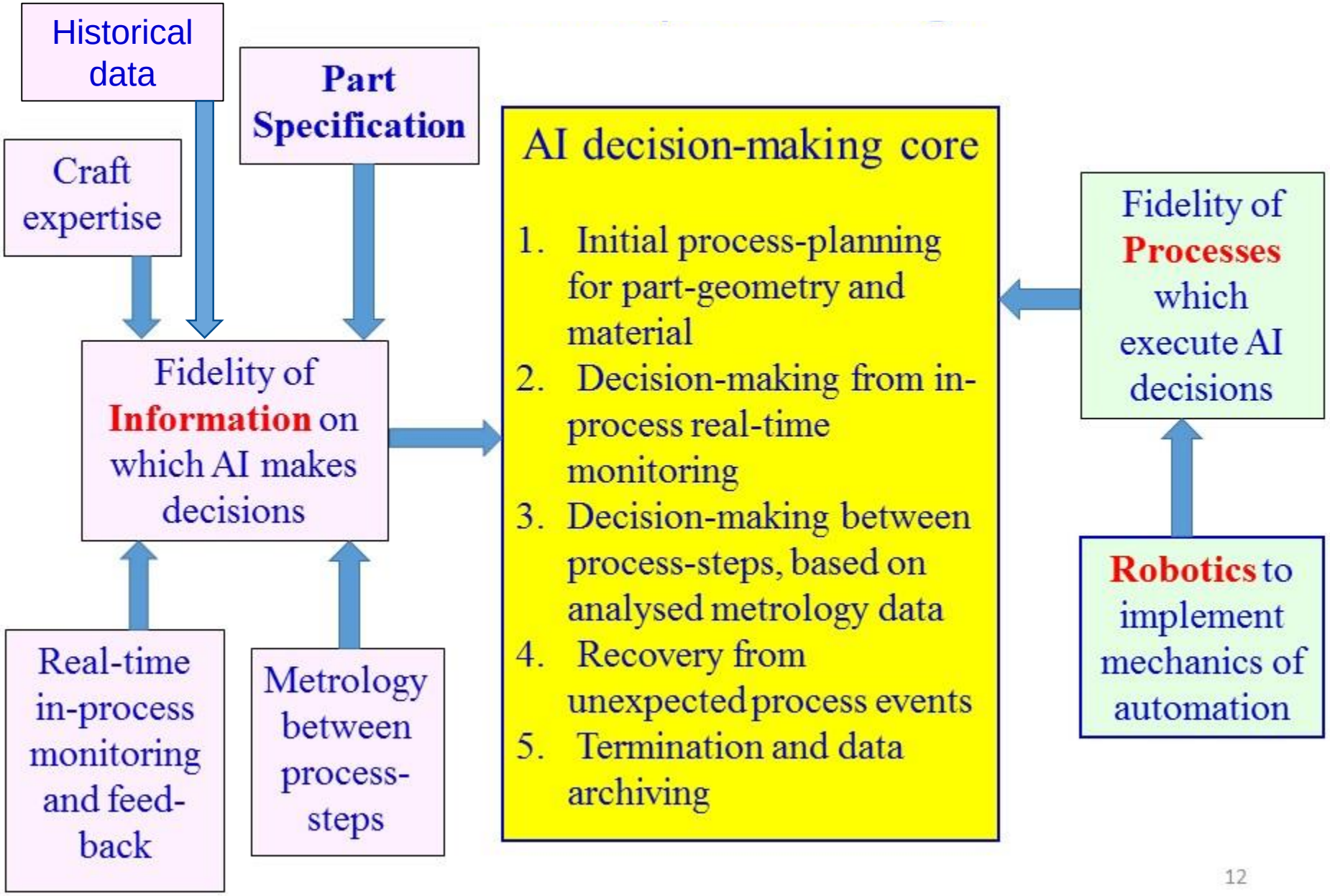
Defining the Problem

- Burgeoning demand for complex, ultraprecision surfaces *… better faster, cheaper*
- Standard CNC machining-centres not good enough
- *Hundreds* of different materials.
- Polishing:- rubbing process – limited predictability, so:
- Iteration process ⟺ metrology to converge on spec.
- With advanced CNC, craft-expertise still needed to:-
  - define process for a new part/material
  - interpret metrology data and ‘tune’ the process
  - respond to unexpected process-events
  - know when to stop!

Crafts-people retiring, in critical short-supply, and taking know-how with them!

Concept of Autonomous Manufacturing Cell.



Main steps in ultra-precision processing

CNC Grinding

Overall geometry + functional surfaces
Output quality: ~ microns rms

Pre-polishing

Functional surfaces
Remove surface & sub-surface damage
Output quality: texture ~ 2 nm Sa, maintain input form

Corrective Polishing

Correct form-errors, maintain texture
Output quality: few nm to 100nm rms

complex hydrodynamic interactions at tool-part interface, dependent upon

- Slurry condition
- abrasive particle size distribution
- knowledge of removal mechanisms
- diversity of substrate materials
- tooling
- Polishing pad
- Tool-path definition
- Speeds & feeds, force
- time

How can we capture craft expertise?

- Interview - think aloud protocol
- Watch them working (human or video)
- Disciplined logging of process operations and decisions
- Digital data-logging of:-
  - machine setup parameters
  - QR-codes on deployed tooling, fixtures etc
  - comprehensive real-time process-variables

Questions for the future:-

Who *owns* captured data, and inferred relationships?
Who has right of *access*, and right of *use?*
What of *remote-diagnostics? product enhancement?*

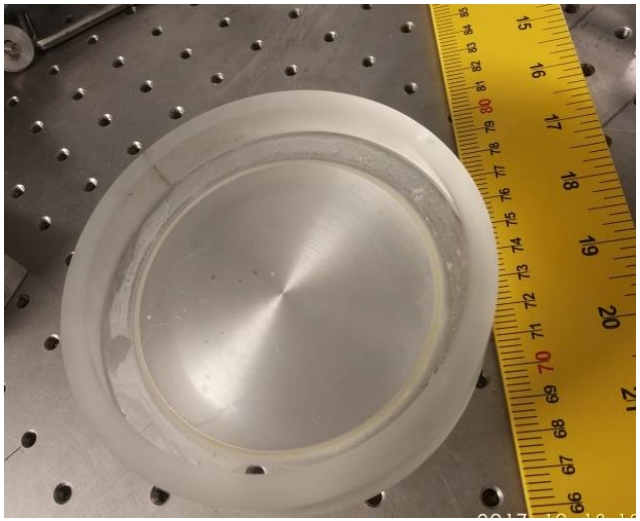
What have we done?

Project case study

Three highly skilled craft-polishers and CNC machinists involved in a Project Case Study.

Real part, real polishing … analyse all steps conducted

Input part



Diameter: 110mm

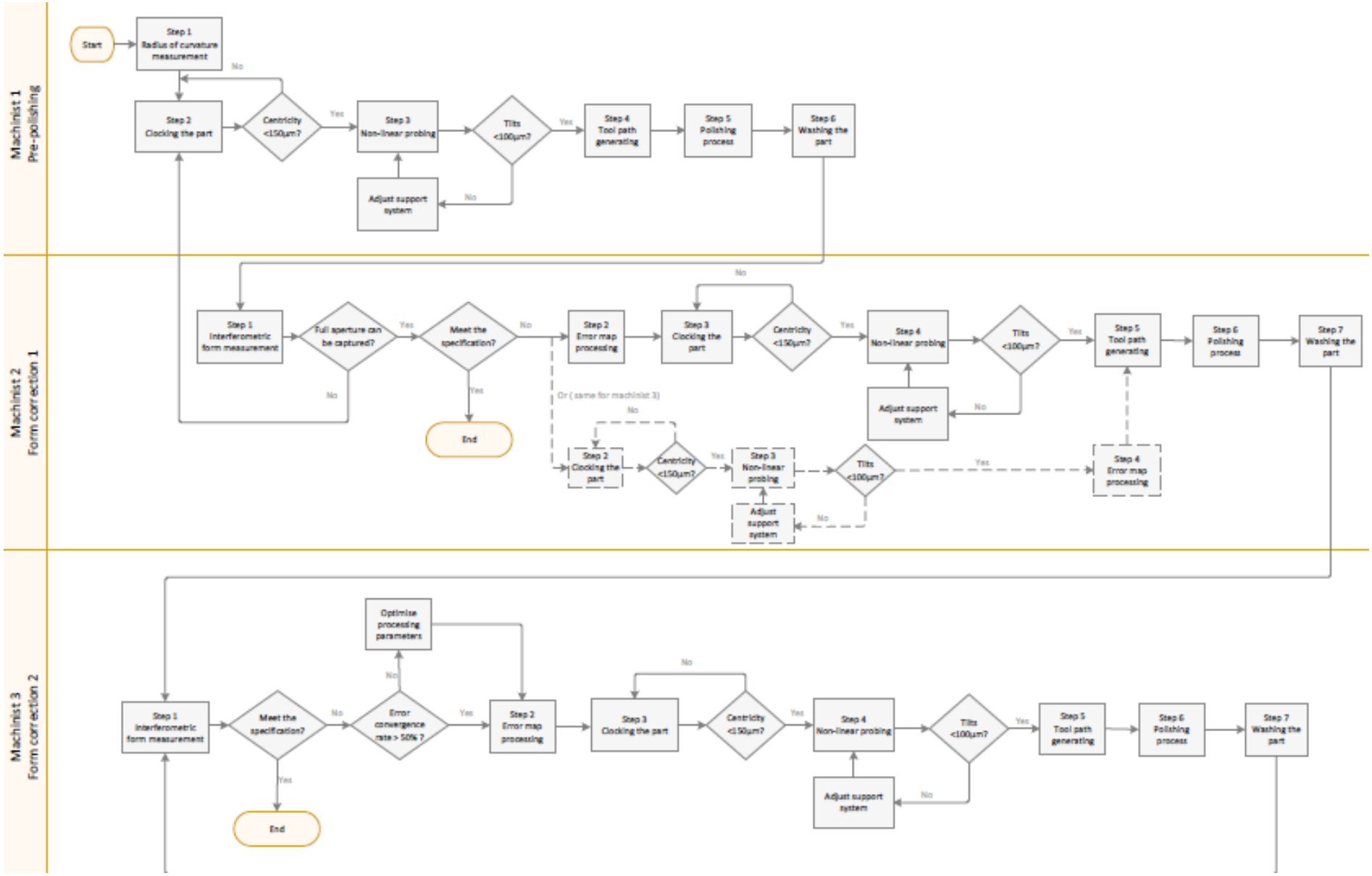
Radius of Curvature: 269mm

Material: BK7 material

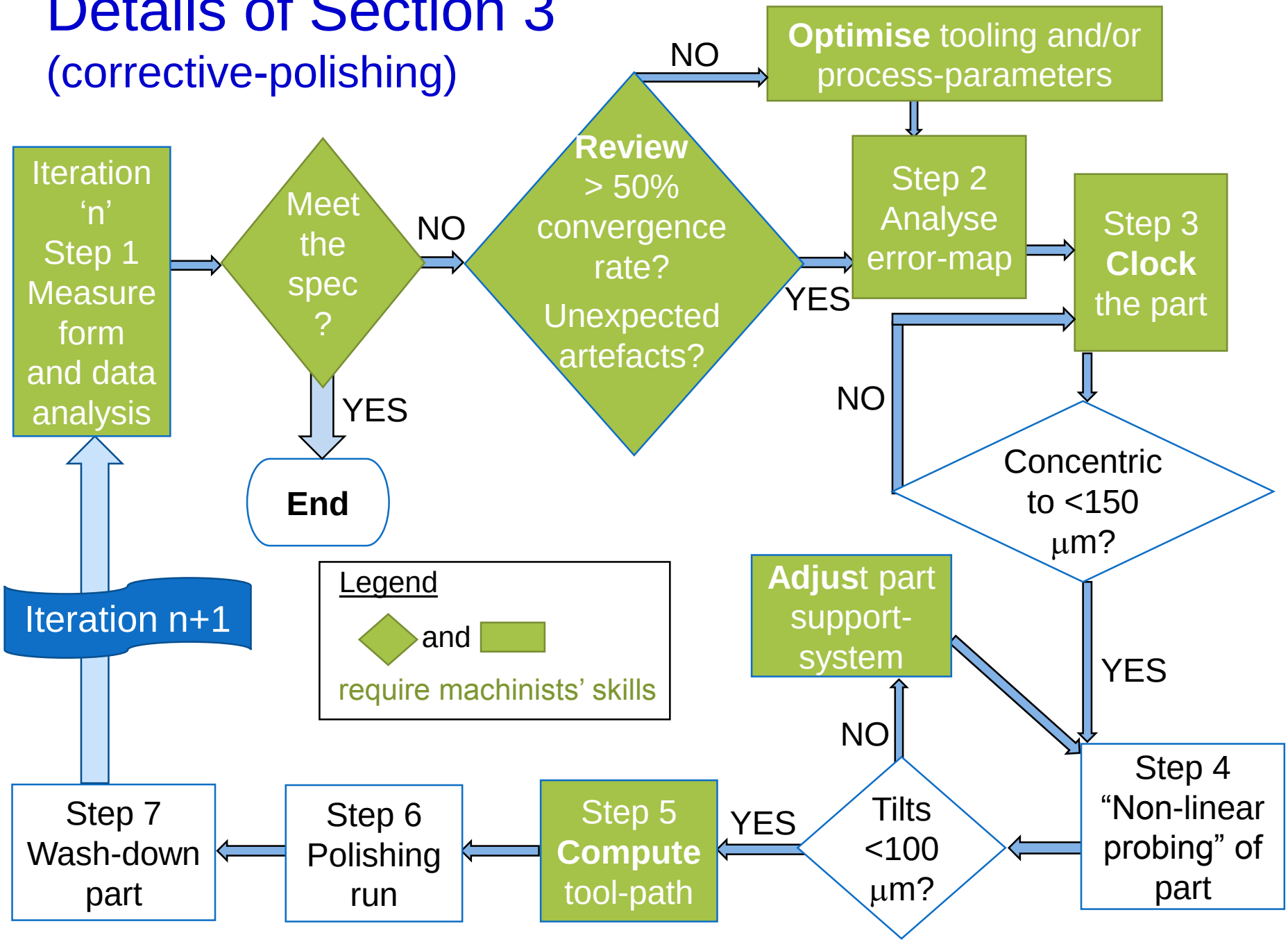
Shape: Concave spherical

- Think aloud protocol.

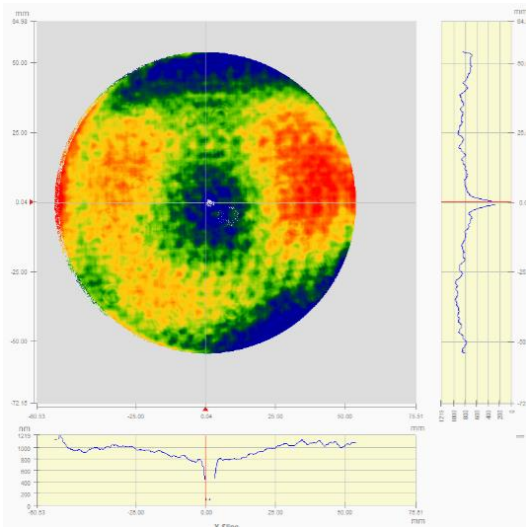
Resulting process flow-chart

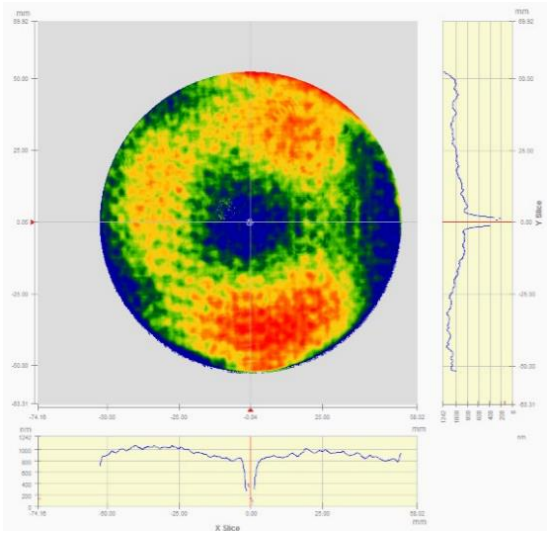


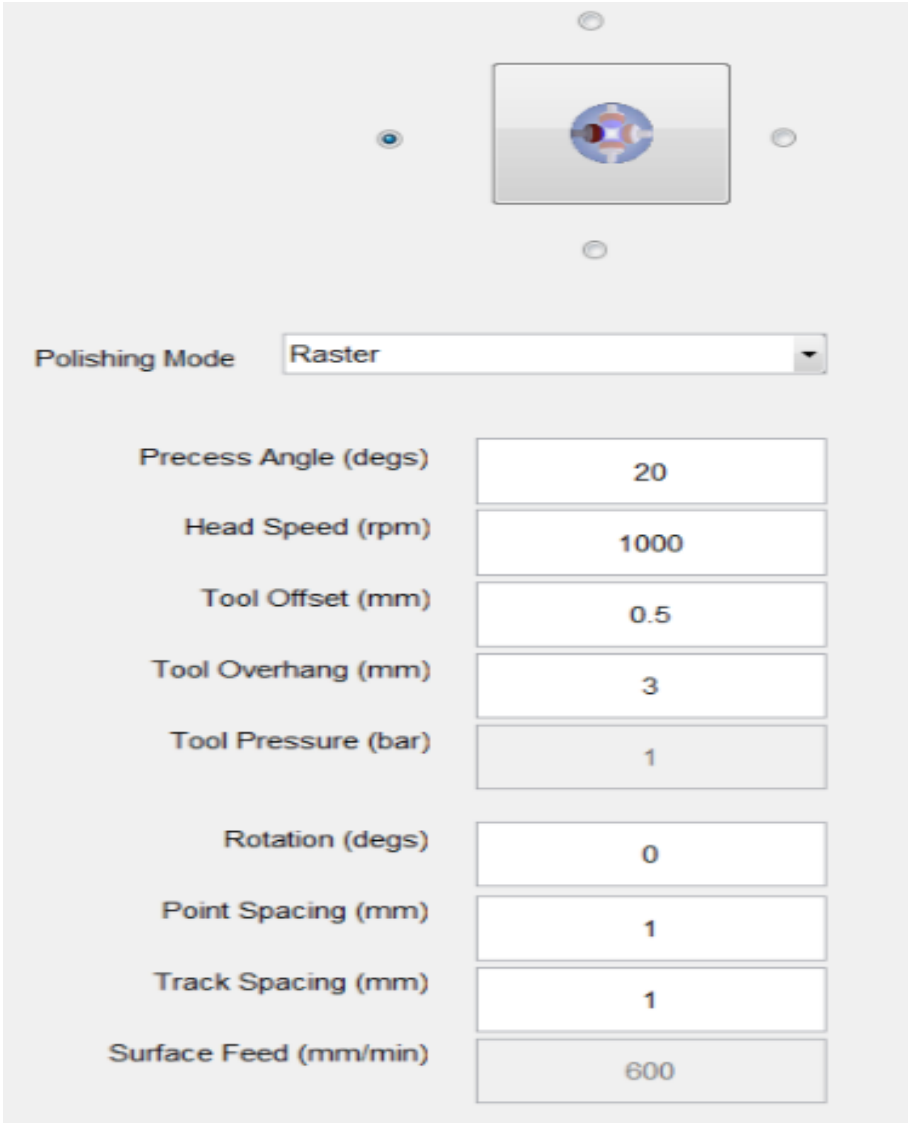
Details of Section 3
(corrective-polishing)



Error-map processing







Knowledge representation

Case-based Reasoning System

Case (optimise processing parameters)

Diameter
Thickness
Radius curvature
Material (implies chemical, thermal and mechanical properties)
Description of the error map

Solution:

Parameters for the machine polishing software
Polishing mode, Precess angle (degs), Head speed (rpm), Tool offset (mm), Tool overhang (mm), Tool pressure (bar), Rotation (degs), Point spacing (mm), Track spacing (mm), Surface feed (mm/min)
Resulting error map

Data bases

Materials Properties

Density
Young's modulus
Thermal exp. coefficient
Fracture toughness
Ductility index
Chemical composition
etc

Historical Process Data

Design specifications
Process parameters
Real-time process data
Metrology results
Operator log

Similarity measure

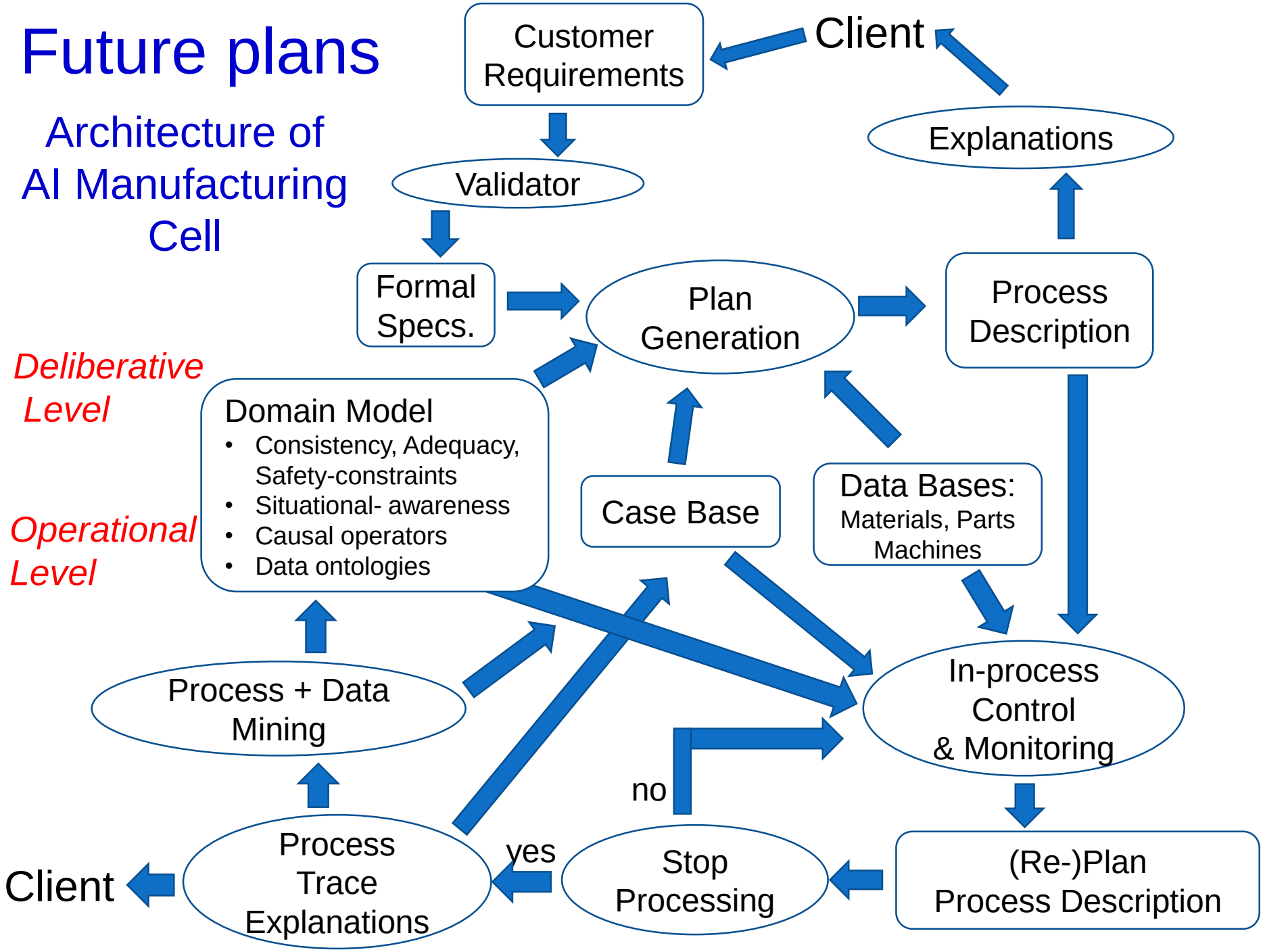
How relevant is a historical case to a new case?

- *Part material* determines tooling, process-conditions and removal-rate.
- Target 3D-form determines tool-path trajectory.
- *k-neighbour similarity* measures the weighted difference between feature values of the new case, and cases from the case-base. Too simple!

- Ontology
  To infer the level of similarity between two concepts,
  - how *specific* are the concepts/values, or
  - what is the level of *commonality* between two compared concepts?

Future plans

Architecture of AI Manufacturing Cell



Summary of project results

Or, *So What?*

- ✓ **Value**: first insights into knowledge/skills of machinists that can realistically be captured from actual crafts operators.

- ✓ **Impact**: first steps to develop AI philosophy embodying capturing crafts expertise, underpins:-
  - – future development of Autonomous Manufacturing Cell:-
    - ○ Generate chains of operations
    - ○ Explain behaviour and logic
    - ○ Diagnose failures; avoid repeated mistakes
    - ○ Self-improve through data-mining