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Software engineering as a model of understanding for learning and problem solving

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Outline

- Introduction
- Software Engineering Cognitive Tools
- The Case Studies
- Comparison
- Conclusions and Future Work

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INTRODUCTION

- Observing young children in schools as they play with games and puzzles, and solve problems.
  - Motivated by the need to try to get a better understanding of the *algorithmic learning process* in order to improve the teaching of software engineering.
- Using Problem-based Learning (PBL) as the environment in first year computer science.
  - Motivated by the need to try to overcome the inherent difficulties first year students have with programming.

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Learning Theories that have influenced our research

- Piaget – Cognitive Structure
- Bruner – Constructivist perspectives of learning
- Guildford – Structure of Intellect
- Gardner – Multiple intelligence
- Papert – Computers and Education
- Schoenfeld – Mathematics as problem-solving
- Bloom – Taxonomy of Educational Objectives

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Software Engineering Cognitive Tools

Refinement

- Refinement is a method of software construction that allows (abstract) specifications to be iteratively refined into other (more concrete) specifications resulting in an efficient implementation.
- Algorithm (process) refinement allows this translation to occur over a procedure or code fragment.
- Data refinement allows the data representation to be translated into a *better* data structure.

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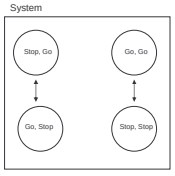
Subclassing: Extension

- Adding an extra state to a system, so that we extend its behaviour. The new system (subclass) does everything the old system (superclass) does, and more.



Traffic Light Example

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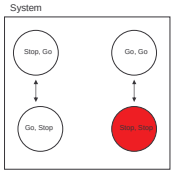
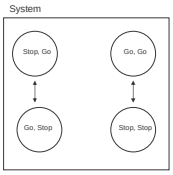


Traffic Light Example

Subclassing: Specialisation



Traffic Light Example

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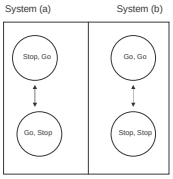


Traffic Light Example

System (a)

The Stop,Go signals alternate and traffic is always flowing, in only 1 direction at a time.

System (b)

Where the traffic is either stopped in both directions or flowing in both directions.

There is no way for the system to move between these 2 separate sub-behaviours. The behaviours of system (a) and system (b) are specialisations of the original system.

Re-Use through Composition

§ Existing software artefacts
  § set of documents and models that are built during the engineering of a software system
    § Analysis, requirements, validation, design, verification, implementation, tests, maintenance, versioning and tools.

are reused, in a wide range of ways, in the construction of a 'new' software system.

Genericity: Universal

§ In software engineering, modelling languages usually provide a means of specifying parameterised behaviour. Typically we see this in the form of a generic data structure.

§ The STACK with 'LIFO' behaviour offered through `push` and `pop` is a classic example.

§ If there exists a generic stack then all you need to do to reuse this, is instantiate the type parameter.

Genericity: Constrained

§ Sorting: we should be able to sort lists of any type of entity provided, there is a way of comparing and ordering any 2 such entities. In effect, we are constrained to sorting only those things that can be sorted.

Re-using or re-usable

- In the traffic light example it would be natural for a software engineer to:
  - Transform the state into a composition of 2 boolean variables in order to *re-use* an already existing well-understood component,
  - Make the traffic light system a *re-usable* component for re-use in larger, more complex systems.

Case Studies

Case study 1 – Searching (in schools)

- Run over a 7 year period, session run 16 times with 16 different classes in 10 different schools.
- Age profile: 6 – 17 years (mean age 13)
- Average class size: 18

Phase 1

- Pre-requisite: Confirming that all children are able to compare the lengths of pieces of string and match those of the same length.

Phase 2

- Hide a number of pieces of string in a number of boxes (one per box), hand the children a piece of string and ask them to find the matching string in one of the boxes. However, they are told that they can only open one box at a time; and that when a box is closed it must contain the piece of string that was in it originally.

Process refinement

- Never look in a box that was already looked in.

Data Refinement

- Boxes searched in an ordered fashion (left to right)
- Boxes already searched are marked with a pencil.
- Boxes moved from a 'not yet examined pile' to an 'examined pile'.

Phase 4

- Order the boxes based on the length of strings within, before asking the children to play the game.
  - Over a period of time the children effectively refine their solution to a binary search.

Phase 5: Generalising the problem

- the strings are replaced by some other physical entity.
- All children manage to generalise the solution for strings to other physical entities which can be ordered in some intuitive fashion.

(This is an example of constrained genericity)

Phase 6: Working with abstraction

Play guess the number (0 – 100), by asking questions to which only the answers *yes* and *no* are allowed.

Some of the children employ the same algorithm for the 'guess the number' as they did for 'find the string'.

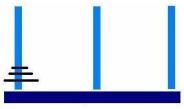
Phase 7: Observing compositional re-use and subclassing (specialisation)

- The number game is altered such that there are 2 numbers that add up to 100, find them both.
  - The original binary search.
  - The calculation of the largest (missing number) as a simple subtraction.
  - A symmetry in the reformulation of their approach in terms of finding the largest (not smallest) element first.

Case study 2: The Tower of Hanoi (University)

- Run over a 2 year period, session run once with 38 different groups.
- Age profile: 18 – 23 years
- Average group size: 5 - 7

- Problem given to students in a Problem-based Learning workshop, in the first week of term.
- Half the groups were given a prop.



- All groups identified the following:-
  - Facts: 3 pegs, n discs of decreasing size
  - Constraints: Move only one disc at a time, cannot place bigger disc on to a smaller disc.

No prop category:- (data refinement and abstraction)

- Discussed different ways to represent the pegs and the discs,
- Investigated the use of chairs, people and books
- Put a label on the discs and the pegs.

Constrained genericity – solving the problem using different entities provided there was a way of comparing these entities in terms of size (larger, smaller)

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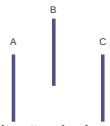
Prop category

§ Relied on the prop to solve the problem, apart from one group who believed the prop was designed incorrectly.



§ They identified a "solution" incorporating a circular pattern, where the moves were refined to be *clockwise* and *anti-clockwise.*

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Solve the problem with the same constraints in less moves?

§ Reduced problem to the simplest instance (1 disc), solved it in two different ways, accepted the solution with the least moves.

§ Increased complexity of problem by adding another disc …….,

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§ Identified a pattern for even numbers and a different pattern for odd numbers.

§ Hypothesised and confirmed their hypothesis for the optimal solution for *n* discs.

(1) moves for *n* = (moves for *n-1*) * 2 + 1

(2) 2^n - 1

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Software engineering techniques:-

§ Process refinement
§ Subclassing and genericity
§ Composition

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Comparison

§ School children (6 – 17 years) and University students (18 – 23 years) demonstrate an implicit understanding of software engineering techniques and *algorithmic understanding*.

§ There are differences in their communication abilities.

§ The size of the groups is different

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§ The time for the sessions is different.

§ The maturity of the students is different.

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Conclusions

§ We observed little difference between children and adults in how they learn about computation.

§ The common framework is usefully modelled using well-understood software engineering techniques.

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Future Work

§ Develop a *theory of problems* that could be used in reasoning about the order in which problems should be presented to CS1 students, and the relationships between these problems.

§ Implement a collect of Java applications for objectively gathering data about the way in which school children solve problems.

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§ Feedback what we have learned from this collaborative research into the sessions we run in schools and with university students.

§ Consolidate our proposal for the theory that:*software engineering provides a good framework for reasoning about how children and adults learn to solve problems.*