4TB3 P0 Extension with Quantifiers

COMP SCI 4TB3 Project- Group 11
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The Goal

- To extend the P0 language with quantified expressions.
- Extensions to be added are:
  - Universal quantifier
  - Array builder
  - Set builder
  - Existential quantifier

Functional Requirements

Requires parsing and code generation for expressions of the following format:

- sorted := all i ∈ 0 .. N - 1 • a[i] ≤ a[i + 1] or sorted := ∀ i ∈ 0 .. N - 1 • a[i] ≤ a[i + 1]
- squares := [i ∈ 0 .. N - 1 • i × i] or squares := [i × i for i ∈ 0 .. N - 1]
- odds := {i ∈ 0 .. N - 1 | i mod 2 = 1 • i} or odds := {i for i ∈ 0 .. N - 1 if i mod 2 = 1}
- found := ∃ i ∈ 0 .. N - 1 • a[i] = x or found := some i ∈ 0 .. N - 1 • a[i] = x

Changes to the P0 Grammar

expression ::= simpleExpression

{("=" | "≠" | "<" | "≤" | ">" | "≥" | "∈" | "⊆" | "⊇") simpleExpression} | quantifiedExpression

quantifiedExpression ::=

("all" | "some" | "∀" | "∃") identRange "•" expression |

"[" { identRange "•" expression | expression "for" identRange } "]" |

"{" { identRange "|" expression "•" expression | expression "for" identRange "if" expression } "}"

identRange ::= ident "∈" expression ".." expression

Changes to Scanner

- The scanner had to be modified to support:
  - `all`, `∀` - Universal quantifier symbols
  - `∃`, `some` - Existential quantifier symbols
  - `•`, `for` - Quantifier expression symbol
  - `|`, `if` - Quantifier condition symbol
  - `{`, `}` - Set builder notation (curly braces)

Changes to Parser

- The parser was extended with the following grammar rules:

identRange ::= ident "∈" expression ".." expression

quantifiedExpression ::= ("all" | "some" | "∀" | "∃") identRange "•" expression |

"[" { identRange "•" expression | expression "for" identRange } "]" |

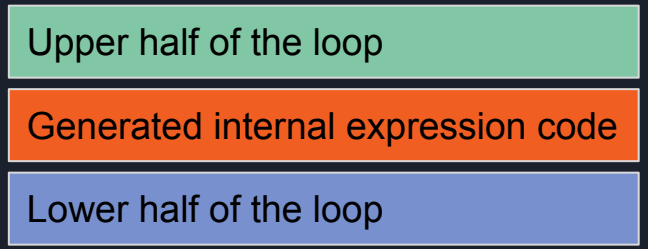
"{" { identRange "|" expression "•" expression | expression "for" identRange "if" expression } "}"

- The implementation required backtracking, to determine the order of supplied arguments and to differentiate from existing notation, namely set definitions like {1, 2, 3}

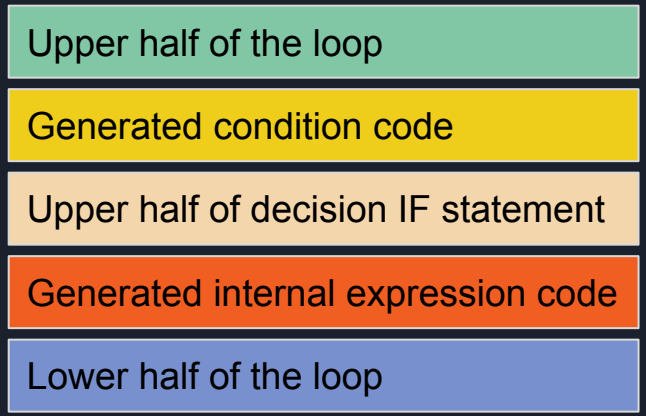
Changes to Code Generator

- Expressions generate to loops instead of a sequence of instructions (unrolled loop)
- Expressions were considered to be generated as function calls, instead are generated as code of current calling function
- Iterated variable declaration and instantiation was considered to be done internally, instead the user is expected to declare iterated variables.
- Code generation was done in two or three code generation functions calls as follows:

Universal, Existential and Array Builder



Set Builder



Testing & Documentation

- Manual testing for robustness and consistency
- Unit testing for future validation
  - SCTest.ipynb
  - P0ParsingTest.ipynb
  - P0TypeCheckingTest.ipynb
  - CGWatTest.ipynb
- Markdown for general descriptions
- In code comments for further explanation

Statistics

File	SC.ipynb	P0.ipynb	CGWat.ipynb	Total
Lines of Code	7	212	158	377
Lines of Documentation	2	16	36	54
Total Lines	9	228	194	431
Test Cases	1	18	8	27

Limitations

- Iteration range bounds have to be constants, to allow for verifying size at compile time, mainly for array assignments.
- Iterator variables have to be declared locally before using them in quantifier expressions.
- Set builder is limited to generating 32-bit bitsets.

Challenges

- Ensuring that the code we write doesn’t interfere with other existing code
- Generating the code, sometimes in 3 segments
- Backtracking to determine the order of operators and to process rules with same literals but different meaning
- Influence of existing code generation on implementation of the extension