Program Transformation

Master Course Program Transformation 2005-2006

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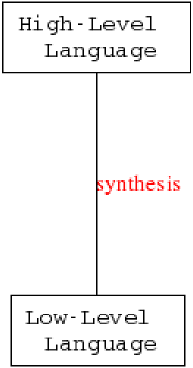
Program Transformation

- *A program transformation is a modification or sequence of modifications to a program* (or an algorithm for making such modifications)
- Taxonomy: classification of program transformations
  - What is the purpose of a transformation?
  - How does it affect a program?
  - What is the relation with other transformations?
- Implementation of program transformation
  - Program transformation by term rewriting
  - and beyond

Program Synthesis



Derive low-level implementation from high-level specification

- Refinement
- Compilation
- Generation

Program Synthesis: Compilation

Tiger

```
function fact(n : int) : int =
  if n < 1 then 1
           else (n * fact(n - 1))
```

⇒

MIPS

```
fact:subu    $sp, $sp, 20
     sw      $fp, 8($sp)
     addiu   $fp, $sp, 20
     sw      $s2, -8($fp)
     sw      $ra, -4($fp)
     sw      $a0, 0($fp)
     move    $s2, $a1
     li      $t0, 1
     bge     $s2, $t0, c_0
     li      $v0, 1
     b       d_0
c_0: lw      $a0, ($fp)
     li      $t0, 1
     subu    $a1, $s2, $t0
     jal     fact_a_0
     mul     $v0, $s2, $v0
d_0: lw      $s2, -8($fp)
     lw      $ra, -4($fp)
     lw      $fp, 8($sp)
     addiu   $sp, $sp, 20
     jr      $ra
```

Program Synthesis: Parser Generation

```
expr   : lam;
lam    : apps | '\\' var '.' lam ;
apps   : simple | apps simple ;
simple : var | num | '(' expr ')' ;
var    : ID;
num    : DIGITS;
```

YACC $\Downarrow$ *C*

```
static const short yypgoto[] = {-32768, 9,-2,-32768,7,12,-32768};
static const short yytable[] = { 1, 2, 3, 1, 4, 1, 2, 14, 18, 4, 1 ...};
int yyparse(YYPARSE_PARAM_ARG) { ...
yyreduce: yylen = yyr2[yyn];
  if (yylen > 0) yyval = yyvsp[1-yylen];  ...
  yystate = yypgoto[yyn - YYNTBASE] + *yyssp;
  if (yystate >= 0 && yystate <= YYLAST && yycheck[yystate] == *yyssp)
    yystate = yytable[yystate];
  else
    yystate = yydefgoto[yyn - YYNTBASE];
  goto yynewstate; ...
}
```

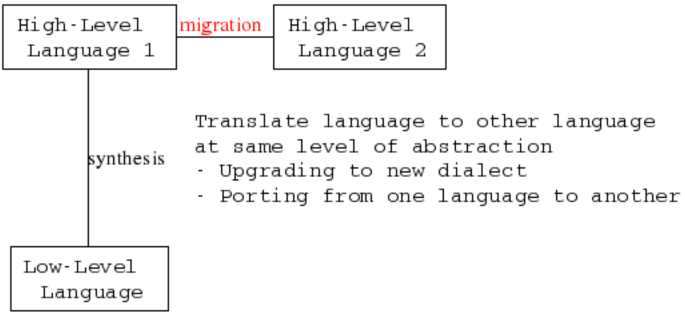
Application Generation

```
Object(
  Name("Reservation"),
  Properties([ Property(Name("Remark"),        Type(Prim(String())))
             , Property(Name("StartDateTime"),  Type(CustomPrim("DateTime"))), ...]),
  Relations( [ Reference(Name("Product"),       Type(Object("Product")))
             , Reference(Name("Customer"),      Type(Object("Customer"))), ...]))
```

DSL ⇓ *Java*

```
public class ReservationRelation extends AbstractDatabase<Reservation, StoredReser...
{
  public List<StoredReservation> read(StoredProduct product, ...) throws ReadException {
    return readList("SELECT " + ALL + " FROM Reservation WHERE productID = " + prod...
  public List<StoredReservation> readWithStartTime (StoredProduct product , Calenda...
    return readList("SELECT " + ALL + "  FROM Reservation WHERE productID = " + pro...
  public ReservationRelation (final JReserveDatabaseDomainObjectLoader loader , fin...
    super(database , new StoredReservationFactory( ) , "Reservation");
    _loader = loader;
    _dispatcher = new StoreDispatcher( ); }
  public void store (Reservation reservation) throws StoreException { ... }
  protected void write (final PreparedStatement stm , final StoredReservation reser...
  protected StoredReservation read(final ResultSet resultSet) throws SQLException {...
}
```

Migration


High-Level
Language 1
migration
High-Level
Language 2
synthesis
Low-Level
Language
Translate language to other language
at same level of abstraction
- Upgrading to new dialect
- Porting from one language to another

Example: Migration from Procedural to OO

```
type tree = {key: int, children: treelist}
type treelist = {hd: tree, tl: treelist}
function treeSize(t : tree) : int =
  if t = nil then 0 else 1 + listSize(t.children)
function listSize(ts : treelist) =
  if ts = nil then 0 else listSize(t.tl)
```

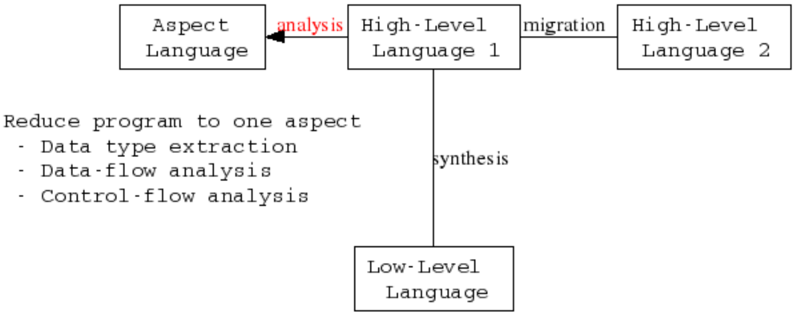
Tiger

$\Downarrow$

```
class Tree {
  Int key;
  TreeList children;
  public Int size() {
    return 1 + children.size
  }
}
class TreeList { ... }
```

Java

Program Analysis

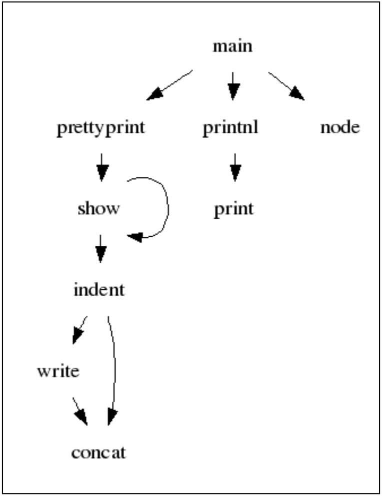


Program Analysis: Call Graph Extraction

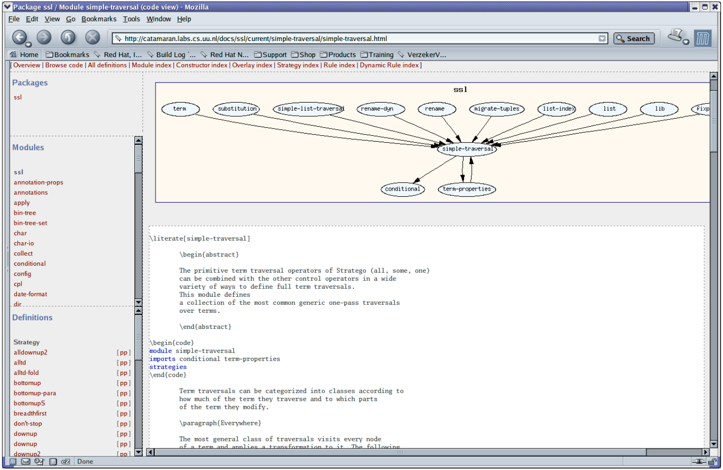
```
type tree = ...
function prettyprint(...) : string =
let function write(s: string) =
    output := concat(...)
  function show(...) =
  let function indent(...) =
        (write(..);
         for i := 1 to n do write(" ");
         output := concat(output, s))
   in if t = nil then indent(".")
      else (...; show(...); ...)
  end
 in show(0, tree); output end
function node(...) : tree =
  tree{key = x, left = l, right = r}
function println(...) =
  (print(x); print("\n"))
in let var t := node(...)
    in println(prettyprint(t)) end
end
```

Tiger

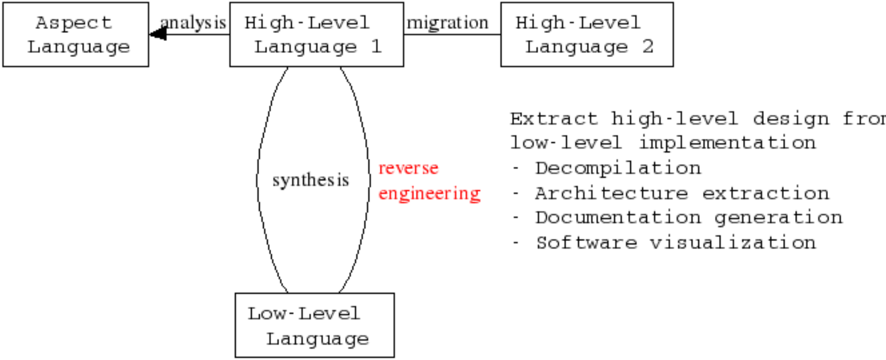
$\Longrightarrow$



Documentation Generation



Reverse Engineering



Example: Goto Elimination

```
       f <- 1
a_0 :  if x > n goto b_3
       x <- x + 1
       f <- f * x
       goto a_0
b_3 :  print(f)
```

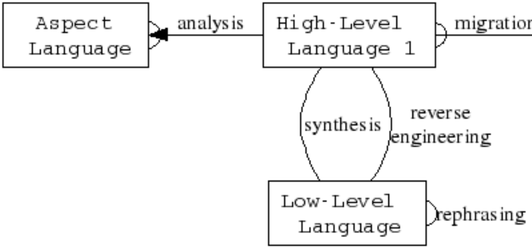
Tiger

$\Rightarrow$

```
f := 1;
while x <= n do (
  x := x + 1;
  f := f * x
);
print(f)
```

Tiger

Program Transformation: Rephrasing



Rephrasing: Normalization

- A normalization reduces a program to a program in a sub-language to decrease its syntactic complexity
- Simplification
  - Algebraic simplifications in compiler
- Desugaring
  - Haskell to Core Haskell
  - EBNF to BNF
- Aspect weaving
  - Tracing
  - Synchronisation

Example: Desugaring Regular Expressions

```
Exp := Id
     |  Id "(" {Exp ","}* ")"
     |  Exp "+" Exp
     |  ...
```

EBNF

$\Rightarrow$

```
Exp  := Id
      |  Id "(" Exps ")"
      |  Exp "+" Exp
      |  ...

Exps :=
      | Expp

Expp := Exp
      |  Expp "," Exp
```

BNF

Example: Desugaring List Comprehensions

```haskell
[ square x | x <- xs; odd x ]
```

Haskell

$\Downarrow$

Haskell

```haskell
let h = \ us -> case us of
                  [] -> []
                  (x : us') -> if odd x
                               then (square x) : (h us')
                               else (h us')
 in h xs
```

Rephrasing: Optimization

- An optimization improves the run-time and/or space performance of a program
- Examples
  - Common subexpression elimination
  - Constant folding and propagation
  - Dead code elimination
  - Fusion: Loop fusion, Deforestation
  - Inlining, Specialization
  - Instruction scheduling
  - Strength reduction
  - Tail-recursion elimination
  - ...

Example: Constant Folding and Propagation

```
var N := 8
var solutions := 0
type intArray = array of int
var row := intArray [ N ] of 0
var col := intArray [ N ] of 0
var diag1 := intArray [N+N-1] of 0
var diag2 := intArray [N+N-1] of 0
```

Tiger

$\Downarrow$

```
var N := 8
var solutions := 0
type intArray = array of int
var row := intArray[8] of 0
var col := intArray[8] of 0
var diag1 := intArray[15] of 0
var diag2 := intArray[15] of 0
```

Tiger

Example: Tail Recursion Elimination

```
function fact(n : int) : int =
  let function f(n : int, acc : int) : int =
        if n < 1 then acc else f(n - 1, n * acc)
   in f(n, 1)
  end
```

Tiger

$\Downarrow$

```
function fact(n : int) : int =
let function f(n : int, acc : int) : int =
      (while n >= 1 do
        (acc := n * acc;
         n := n - 1);
       acc)
in f(n, 1)
end
```

Tiger

Example: Inlining

```
function fact(n : int) : int =
let function f(n : int, acc : int) : int =
      (while n >= 1 do
        (acc := n * acc;
         n := n - 1);
       acc)
in f(n, 1)
end
```

Tiger

$\Downarrow$

```
function fact(n : int) : int =
let var acc : int := 1
 in while n >= 1 do
      (acc := n * acc;
       n := n - 1);
    acc
end
```

Tiger

Example: Partial Evaluation

```
function power(x : int, n : int) : int =
  if n = 0 then 1
  else if even(n) then square(power(x, n/2))
  else (x * power(x, n - 1))
```

Tiger

$\Downarrow$ `n = 5`

Tiger

```
function power5(x : int) : int =
  x * square(square(x))
```

Example: Strength Reduction

```
x := 0;
while x < n do (
  x := x + 1;
  s := i * x;
  f(s)
)
```

Tiger

$\Rightarrow$

```
x := 0;
s := 0;
while x < n do (
  x := x + 1;
  s := s + i;
  f(s)
)
```

Tiger

Example: Vectorization

```
DO I = 1, N
  DO J = 1, N
    C(J,I) = 0.0
    DO K = 1, N
      C(J,I) = C(J,I) + A(J,K) * B(K,I)
    ENDDO
  ENDDO
ENDDO
```

FORTRAN90

$\Downarrow$

```
DO I = 1, N
  DO J = 1, N, 64
    C(J:J+63,I) = 0.0
    DO K = 1, N
      C(J:J+63,I) = C(J:J+63,I) + A(J:J+63,K) * B(K,I)
    ENDDO
  ENDDO
ENDDO
```

FORTRAN90

Rephrasing: Refactoring

- A refactoring changes the structure of the program to make it easier (or harder) to understand
- Preserves observable behavior
- Design improvement
  - Extract method
  - Move method
  - Inline method
- Obfuscation
  - Hide business rules

Example: Extract Method

```
void printOwing() {
  printBanner();
  //print details
  System.out.println ("name: " + _name);
  System.out.println ("amount " + getOutstanding());
}
```

Java $\Downarrow$ Java

```
void printOwing() {
  printBanner();
  printDetails(getOutstanding());
}
void printDetails (double outstanding) {
  System.out.println ("name: " + _name);
  System.out.println ("amount " + outstanding);
}
```

Rephrasing: Renovation

- Software renovation is used to
  - Repair an error
  - Bring a program up to date with respect to changed requirements
- Does not preserve semantics
- Error Repair
  - Year 2000
- Changed requirements
  - Euro
  - Changed product

Example: Picture Widening

```
IDENTIFICATION DIVISION.
PROGRAM-ID. EXPANDPICTURE.
DATA DIVISION.

WORKING-STORAGE SECTION.
01  PRODKODE PIC 99.
01  X PIC 9(2).
01  Y PIC 9(2).

PROCEDURE DIVISION.
FOO SECTION.
PAR1.
  MOVE PRODKODE TO X.
```

COBOL

```
IDENTIFICATION DIVISION.
PROGRAM-ID. EXPANDCONSTANT.
DATA DIVISION.

WORKING-STORAGE SECTION.
01  PRODKODE PIC 999.
01  X PIC 9(3).
01  Y PIC 9(2).

PROCEDURE DIVISION.
FOO SECTION.
PAR1.
  MOVE PRODKODE TO X.
```

COBOL

Program Transformation Scenarios

- **Translation**: Translate program in source language A to program in target language B
  - Migration
  - Synthesis
  - Reverse engineering
  - Analysis
- **Rephrasing**: Transform program in source language A to program in the same language
  - Normalization
  - Optimization
  - Refactoring
  - Renovation

Summary

A program transformation is a modification or sequence of modifications affecting the

- level of abstraction,
- implementation language,
- performance,
- understandability,
- correctness, or
- scope

of a program

Summary

with the purpose to

- understand a program
- support a different platform
- produce efficient implementation
- improve/hide the design of a program
- update a program to new requirements
- derive a high-level specification from an implementation
- generate an implementation from a high-level specification

Synonyms for 'Program Transformation'

- Meta-programming
  - synonym for program transformation (programming about programming)
- Generative programming
  - programming methodology based on program generation
- Program synthesis
  - (automatically) 'synthesizing' a program
- Program refinement
  - refining a specification to an implementation
- Program calculation
  - (manually) applying semantic laws to 'compute' a program

Sources

Examples on these slides are derived from various sources, including:

- Andrew Appel. *Modern Compiler Implementation in ML*
- Neil Jones, Carsten K. Gomar and Peter Sestoft. *Partial Evaluation and Automatic Program Generation*
- Martin Fowler. *Refactoring. Improving the Design of Existing Code*
- Randy Allen and Ken Kennedy. *Optimizing Compilers for Modern Architectures*