Konstrukcija kompilatora

— Troadresni kod —

Milena Vujošević Janičić

www.matf.bg.ac.rs/~milena

Matematički fakultet, Univerzitet u Beogradu

Pregled

Pregled

Troadresni kod

- Troadresni kod - međureprezentacija visokog nivoa u kojoj svaki operacija ima najviše tri operanda
- U trenutku generisanja troadresnog koda nije bitno misliti na njegovu optimizaciju
- U redu je da taj kod sadrži dodele viška i redudantna izračunavanja - to će biti eliminisano u fazi optimizacije
- Razmatraćemo stek izvršavanja i virtuelne tabele

Sample TAC Code

```
int x;
int y;

int x2 = x * x;
int y2 = y * y;
int r2 = x2 + y2;
```

Sample TAC Code

```
int x;
int y;

int x2 = x * x;
int y2 = y * y;
int r2 = x2 + y2;
```

```
x2 = x * x;
y2 = y * y;
r2 = x2 + y2;
```

Sample TAC Code

```
int a;
int b;
int c;
int d;

a = b + c + d;
b = a * a + b * b;
```

Sample TAC Code

```
int a;
int b;
int c;
int d;

a = b + c + d;
b = a * a + b * b;
```

```
_t0 = b + c;
a = _t0 + d;
_t1 = a * a;
_t2 = b * b;
b = _t1 + _t2;
```

Sample TAC Code

```
int a;
int b;
int c;
int d;

a = b + c + d;
b = a * a + b * b;
```

```
_t0 = b + c;
a = _t0 + d;
_t1 = a * a;
_t2 = b * b;
b = _t1 + _t2;
```

Privremene promenljive

- Tri u troadresnom kodu označava broj operanada proizvoljne instrukcije
- Evaluacija izraza sa više od tri podizraza zahteva uvođenje privremenih promenljivih
- Videćemo postupak uskoro

Sample TAC Code

```
int a;
int b;

a = 5 + 2 * b;
```

Sample TAC Code

```
int a;
int b;

a = 5 + 2 * b;
```

```
_t0 = 5;
_t1 = 2 * b;
a = _t0 + _t1;
```

Sample TAC Code

```
int a;
int b;

a = 5 + 2 * b;
```

TAC allows for instructions with two operands.

```
_t0 = 5;
_t1 = 2 * b;
a = _t0 + _t1;
```

Troadresni kod

- Razmatraćemo pojednostavljeni troadresni kod u kojem su dozvoljene naredne dodele

```
var   = constant;
var_1 = var_2 ;
var_1 = var_2 op var_3 ;
var_1 = constant op var_2 ;
var_1 = var_2 op constant;
var   = constant_1 op constant_2 ;
```

- Dozvoljeni operatori $+, -, *, /, \%$
- Kako biste preveli `y = -x;` ?

Troadresni kod

- Razmatraćemo pojednostavljeni troadresni kod u kojem su dozvoljene naredne dodele

```
var   = constant;
var_1 = var_2 ;
var_1 = var_2 op var_3 ;
var_1 = constant op var_2 ;
var_1 = var_2 op constant;
var   = constant_1 op constant_2 ;
```

- Dozvoljeni operatori $+, -, *, /, \%$
- Kako biste preveli `y = -x;` ?

```
y = 0 - x;
y = -1 * x;
```

One More with `bool`s

```
int x;
int y;
bool b1;
bool b2;
bool b3;

b1 = x + x < y
b2 = x + x == y
b3 = x + x > y
```

One More with `bool`s

```
int x;
int y;
bool b1;
bool b2;
bool b3;

b1 = x + x < y
b2 = x + x == y
b3 = x + x > y
```

```
_t0 = x + x;
_t1 = y;
b1 = _t0 < _t1;

_t2 = x + x;
_t3 = y;
b2 = _t2 == _t3;

_t4 = x + x;
_t5 = y;
b3 = _t5 < _t4;
```

TAC sa bool vrednostima

- Bulovske promenljive se predstavljaju kao celobrojne vrednosti koje mogu imati vrednost nula ili vrednost različitu od nule
- Pored aritmetičkih operatora, podržavamo i $<$, `==`, `||` i `&&`
- Kako bi moglo da se prevede `b = (x <= y)` ?

TAC sa bool vrednostima

- Bulovske promenljive se predstavljaju kao celobrojne vrednosti koje mogu imati vrednost nula ili vrednost različitu od nule
- Pored aritmetičkih operatora, podržavamo i `<`, `==`, `||` i `&&`
- Kako bi moglo da se prevede `b = (x <= y)` ?

```
_t0 = x < y;
_t1 = x == y;
b = _t0 || _t1;
```

Labele

- Imenovane labele označavaju određene delove koda na koje se može skočiti
- Mogu postojati razne instrukcije za kontrolu toka
- `Goto label;` — bezuslovni skok
- `ifZ value goto label;` — uslovni skok, `ifZ` je uvek upareno sa `Goto label`

Control Flow Statements

```
int x;
int y;
int z;

if (x < y)
   z = x;
else
   z = y;

z = z * z;
```

Control Flow Statements

```
int x;
int y;
int z;

if (x < y)
   z = x;
else
   z = y;

z = z * z;
```

```
     _t0 = x < y;
     IfZ _t0 Goto _L0;
     z = x;
     Goto _L1;
_L0:
     z = y;
_L1:
     z = z * z;
```

Control Flow Statements

```
int x;
int y;
int z;

if (x < y)
   z = x;
else
   z = y;

z = z * z;
```

```
     _t0 = x < y;
     IfZ _t0 Goto _L0;
     z = x;
     Goto _L1;
_L0:
     z = y;
_L1:
     z = z * z;
```

Control Flow Statements

```
int x;
int y;
int z;

if (x < y)
   z = x;
else
   z = y;

z = z * z;
```

```
     _t0 = x < y;
     IfZ _t0 Goto _L0;
     z = x;
     Goto _L1;
_L0:
     z = y;
_L1:
     z = z * z;
```

Control Flow Statements

```
int x;
int y;

while (x < y) {
   x = x * 2;
}

y = x;
```

Control Flow Statements

```
int x;
int y;

while (x < y) {
   x = x * 2;
}

y = x;
```

```
_L0:
    _t0 = x < y;
    IfZ _t0 Goto _L1;
    x = x * 2;
    Goto _L0;
_L1:
    y = x;
```

Kompilacija funkcija

- Funkcije se sastoje iz četiri dela:
  - Labela koja označava početak funkcije
  - Instrukcija `BeginFunc NB;` koja rezerviše NB bajtova za prostor za lokalne i privremene promenljive
  - Telo funkcije
  - Instrukcija `EndFunc` koja obeležava kraj funkcije, kada se do nje dođe ona je zadužena da počisti stek okvir i da vrati kontrolu na odgovarajuće mesto

A Complete Decaf Program

```
void main() {
   int x, y;
   int m2 = x * x + y * y;

   while (m2 > 5) {
      m2 = m2 - x;
   }
}
```

A Complete Decaf Program

```
void main() {
   int x, y;
   int m2 = x * x + y * y;

   while (m2 > 5) {
      m2 = m2 - x;
   }
}
```

```
main:
   BeginFunc 24;
   _t0 = x * x;
   _t1 = y * y;
   m2 = _t0 + _t1;
_L0:
   _t2 = 5 < m2;
   IfZ _t2 Goto _L1;
   m2 = m2 - x;
   Goto _L0;
_L1:
   EndFunc;
```

A Complete Decaf Program

```
void main() {
   int x, y;
   int m2 = x * x + y * y;

   while (m2 > 5) {
      m2 = m2 - x;
   }
}
```

```
main:
   BeginFunc 24;
   _t0 = x * x;
   _t1 = y * y;
   m2 = _t0 + _t1;
_L0:
   _t2 = 5 < m2;
   IfZ _t2 Goto _L1;
   m2 = m2 - x;
   Goto _L0;
_L1:
   EndFunc;
```

A Complete Decaf Program

```
void main() {
   int x, y;
   int m2 = x * x + y * y;

   while (m2 > 5) {
      m2 = m2 - x;
   }
}
```

```
main:
   BeginFunc 24;
   _t0 = x * x;
   _t1 = y * y;
   m2 = _t0 + _t1;
_L0:
   _t2 = 5 < m2;
   IfZ _t2 Goto _L1;
   m2 = m2 - x;
   Goto _L0;
_L1:
   EndFunc;
```

A Complete Decaf Program

```
void main() {
   int x, y;
   int m2 = x * x + y * y;

   while (m2 > 5) {
      m2 = m2 - x;
   }
}
```

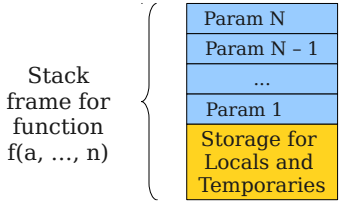
```
main:
   BeginFunc 24;
   _t0 = x * x;
   _t1 = y * y;
   m2 = _t0 + _t1;
_L0:
   _t2 = 5 < m2;
   IfZ _t2 Goto _L1;
   m2 = m2 - x;
   Goto _L0;
_L1:
   EndFunc;
```

Upravljanje stekom u TACu

Podsetnik:

- Funkcija pozivalac je odgovorna za smeštanje argumenata funkcije na stek
- Pozvana funkcija je odgovorna za smeštanje svojih lokalnih i privremenih promenljivih

A Logical Decaf Stack Frame



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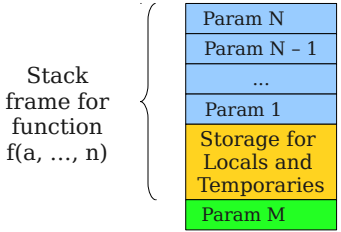

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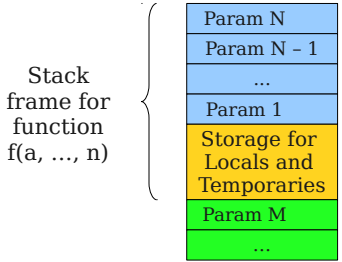

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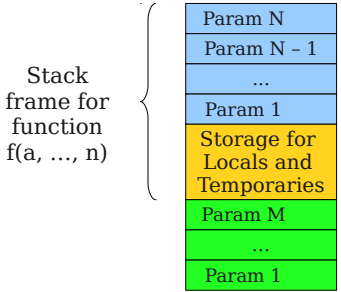

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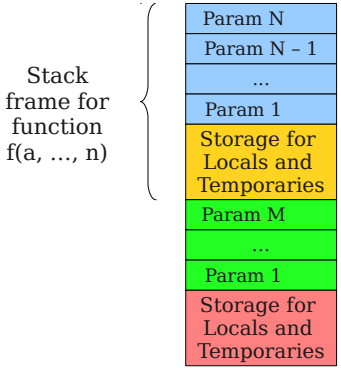

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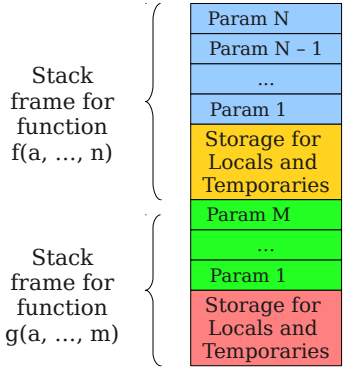

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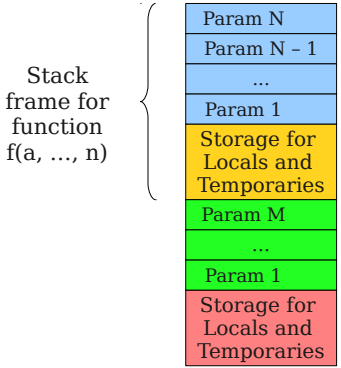

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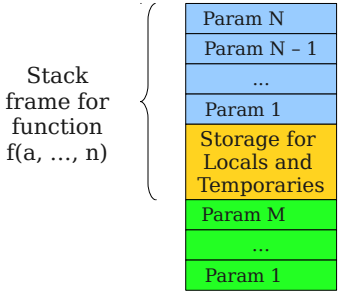

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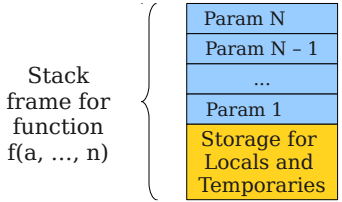

Upravljanje stekom u TACu

- Instrukcija `BeginFunc NB;` rezerviše prostor za lokalne i privremene promenljive
- Instrukcija `EndFunc;` vraća prostor koji je rezervisan sa `BeginFunc NB;`
- U narednom primeru, jedan parametar je gurnut na stek od strane pozivaoca korišćenjem instrukcije `PushParam var`
- U narednom primeru, prostor je oslobođen od strane pozivaoca korišćenjem instrukcije `PopParams NB;`
- `NB` je broj bajtova (nije broj argumenata, na slikama je obleženo sa N)!

Compiling Function Calls

```
void SimpleFn(int z) {
    int x, y;
    x = x * y * z;
}

void main() {
   SimpleFunction(137);
}
```

Compiling Function Calls

```
void SimpleFn(int z) {
    int x, y;
    x = x * y * z;
}

void main() {
   SimpleFunction(137);
}
```

```
_SimpleFn:
   BeginFunc 16;
   _t0 = x * y;
   _t1 = _t0 * z;
   x = _t1;
   EndFunc;
```

Compiling Function Calls

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void SimpleFn(int z) {
    int x, y;
    x = x * y * z;
}

void main() {
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Compiling Function Calls

```
void SimpleFn(int z) {
    int x, y;
    x = x * y * z;
}

void main() {
   SimpleFunction(137);
}
```

```
_SimpleFn:
    BeginFunc 16;
    _t0 = x * y;
    _t1 = _t0 * z;
    x = _t1;
    EndFunc;

main:
    BeginFunc 4;
    _t0 = 137;
    PushParam _t0;
    LCall _SimpleFn;
    PopParams 4;
    EndFunc;
```

Compiling Function Calls

```
void SimpleFn(int z) {
    int x, y;
    x = x * y * z;
}

void main() {
   SimpleFunction(137);
}
```

```
_SimpleFn:
    BeginFunc 16;
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    _t1 = _t0 * z;
    x = _t1;
    EndFunc;

main:
    BeginFunc 4;
    _t0 = 137;
    PushParam _t0;
    LCall _SimpleFn;
    PopParams 4;
    EndFunc;
```

Compiling Function Calls

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void SimpleFn(int z) {
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    PopParams 4;
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```

Compiling Function Calls

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void SimpleFn(int z) {
    int x, y;
    x = x * y * z;
}

void main() {
   SimpleFunction(137);
}
```

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    _t1 = _t0 * z;
    x = _t1;
    EndFunc;

main:
    BeginFunc 4;
    _t0 = 137;
    PushParam _t0;
    LCall _SimpleFn;
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```

Compiling Function Calls

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void SimpleFn(int z) {
    int x, y;
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    _t0 = 137;
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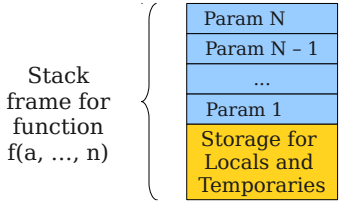
A Logical Decaf Stack Frame



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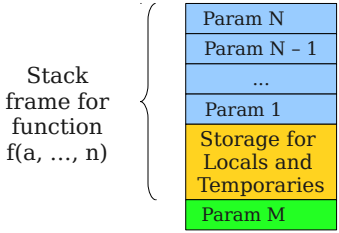
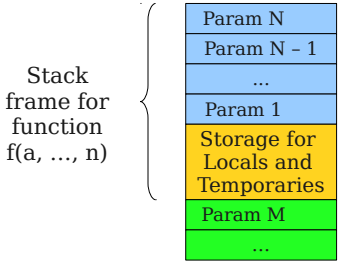


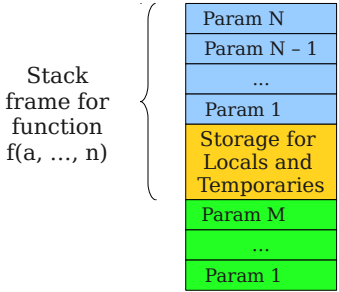
`PushParam` *`var`*`;`

A Logical Decaf Stack Frame



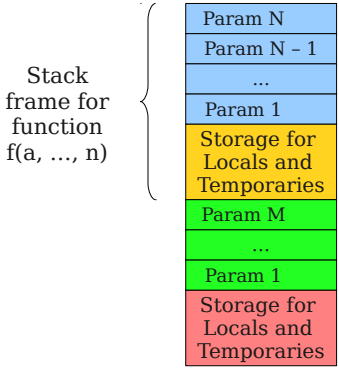

```
PushParam var;
PushParam var;
```

A Logical Decaf Stack Frame



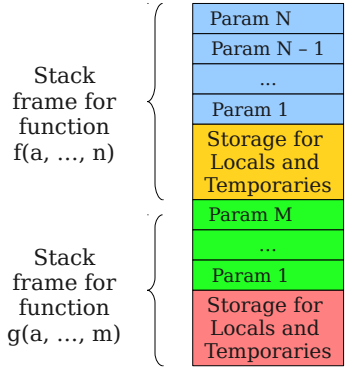

```
PushParam var;
PushParam var;
PushParam var;
```

A Logical Decaf Stack Frame



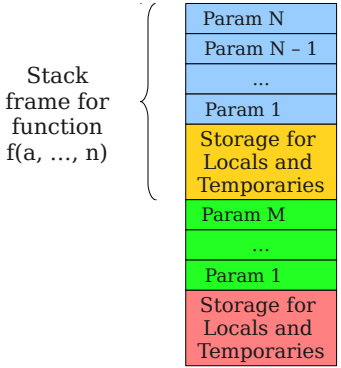

```
PushParam var;
PushParam var;
PushParam var;
BeginFunc N;
```

A Logical Decaf Stack Frame




```
PushParam var;
PushParam var;
PushParam var;
BeginFunc N;
```

A Logical Decaf Stack Frame



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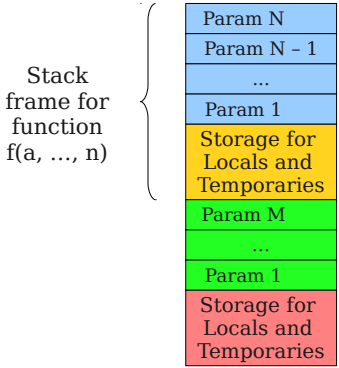
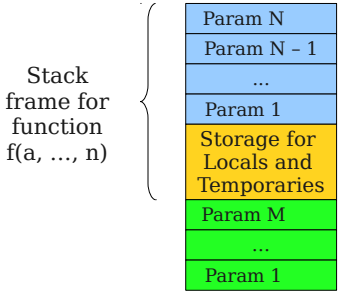



```
EndFunc;
```

A Logical Decaf Stack Frame



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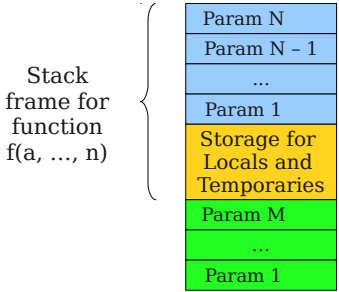
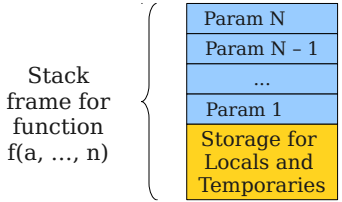


`PopParams N;`

A Logical Decaf Stack Frame



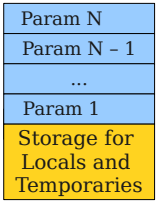
Frame pointer

- Obratiti pažnju da `N` sa desne strane nije isto što i broj parametara funkcije `f`, već odgovara broju bajtova koja je potrebno rezervisati/osloboditi. Ima različite vrednosti za `BeginFunc N` i `PopParams N` (nije isto `N` u ta dva slučaja, samo je oznaka ista).
  - Za `BeginFunc N`, `N` odgovara broju bajtova koji su potrebni za lokalne i privremene promenljive funkcije,
  - Za `PopParams N`, `N` odgovara broju bajtova koje su argumenti `Param M` ... `Param 1` zauzimali

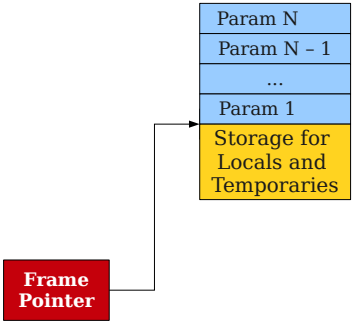
Frame pointer

- Prethodni prikazi su bili prikazi logičkih stek okvira,
- Da bi se implementirao stek, potrebno je čuvati dodatne informacije
- Pre svega, potrebno je znati gde se nalaze lokalne promenljive, parametri i privremene promenljive
- One se čuvaju u odnosu na *frame pointer* fp

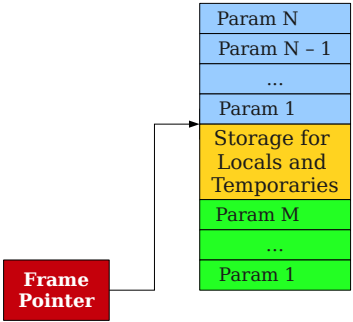
The Frame Pointer



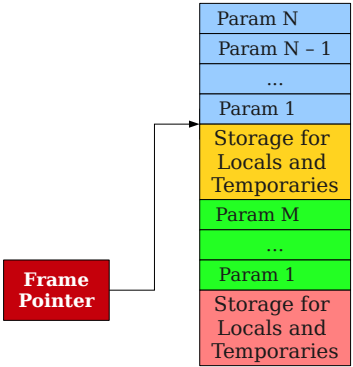
The Frame Pointer



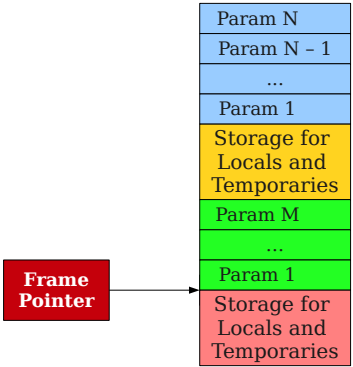
The Frame Pointer



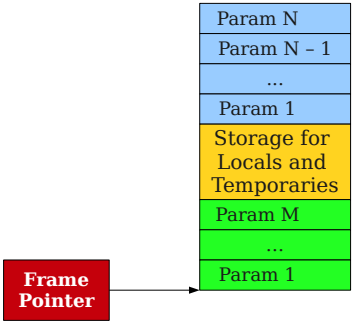
The Frame Pointer



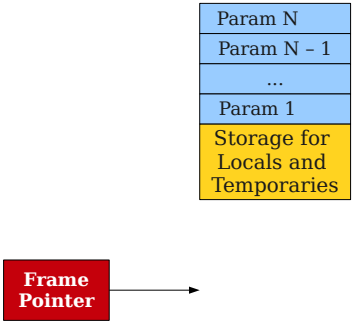
The Frame Pointer



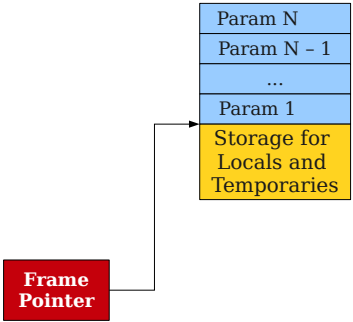
The Frame Pointer



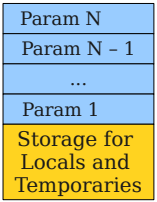
The Frame Pointer



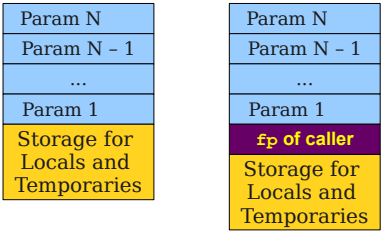
The Frame Pointer



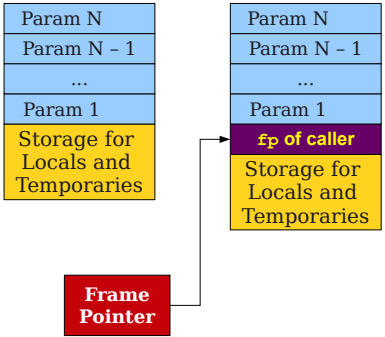
Logical vs Physical Stack Frames



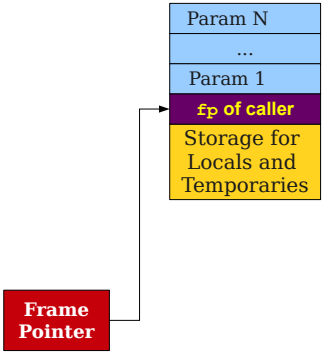
Logical vs Physical Stack Frames



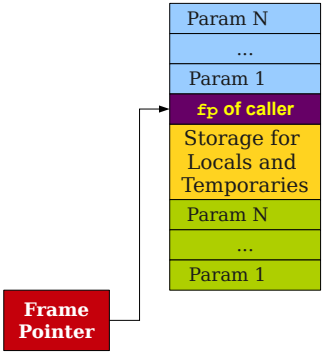
Logical vs Physical Stack Frames



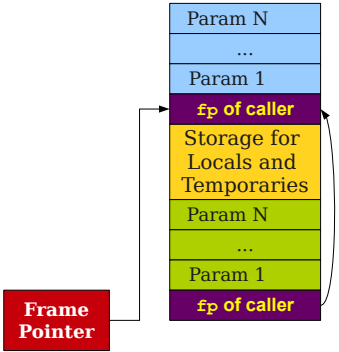
(Mostly) Physical Stack Frames



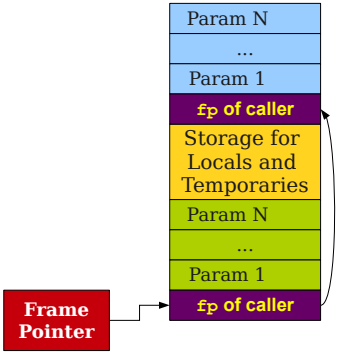
(Mostly) Physical Stack Frames



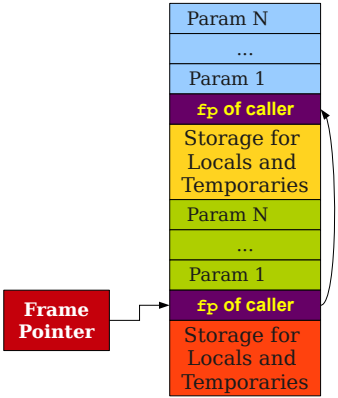
(Mostly) Physical Stack Frames



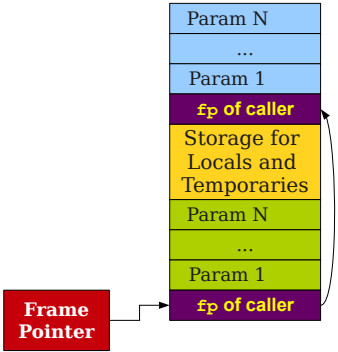
(Mostly) Physical Stack Frames



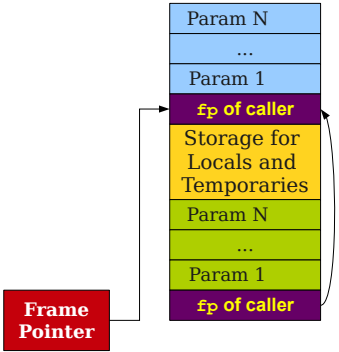
(Mostly) Physical Stack Frames



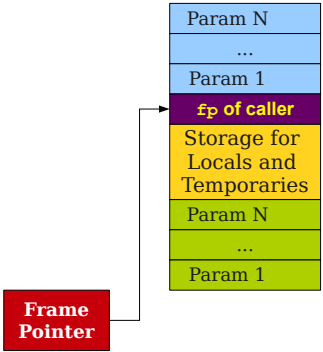
(Mostly) Physical Stack Frames



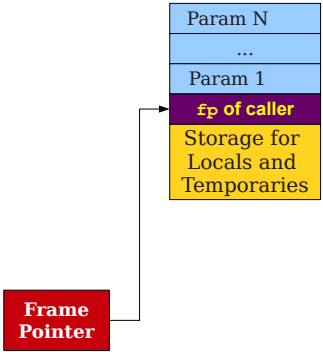
(Mostly) Physical Stack Frames



(Mostly) Physical Stack Frames



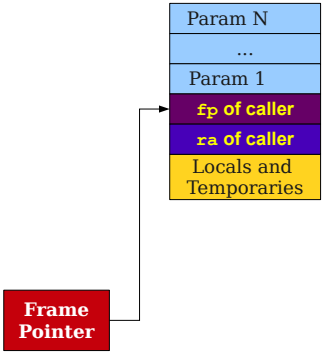
(Mostly) Physical Stack Frames



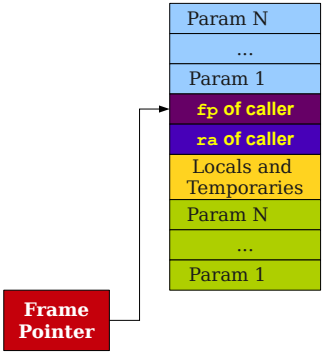
Dodatne informacije u stek okviru

- Interno, procesor ima specijalni registar koji se naziva brojač instrukcija *program counter* (PC) koji čuva adresu naredne instrukcije koja treba da se izvrši
- Kad kôd funkcije završi sa radom, potrebno je da se PC podesi tako da se nastavi izvršavanje funkcije tamo gde je ono bilo prekinuto
- Adresa gde je potrebno funkcija da se vrati se drugačije čuva na različitim platformama. Na primer u okviru MIPS platforme ona se čuva u okviru specijalnog registra koji se zove `ra` (*return address*)
- To omogućava MIPS funkcijama da budu pozvane: svaka funkcija treba da sačuva prethodnu vrednost od ra

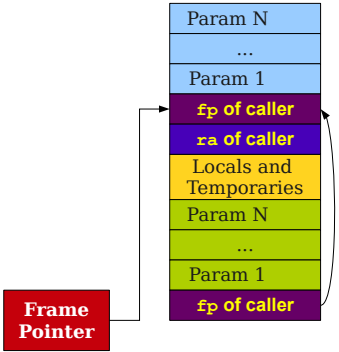
Physical Stack Frames



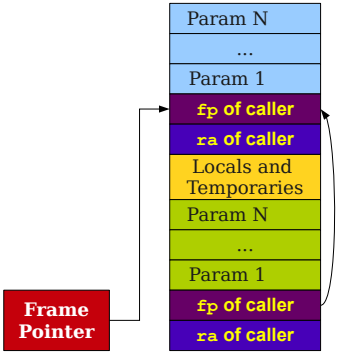
Physical Stack Frames



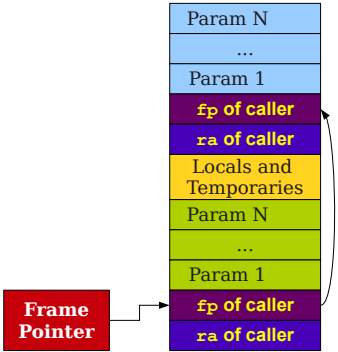
Physical Stack Frames



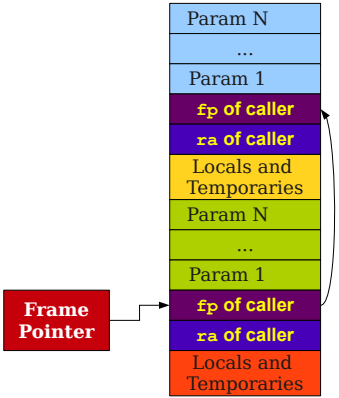
Physical Stack Frames



Physical Stack Frames

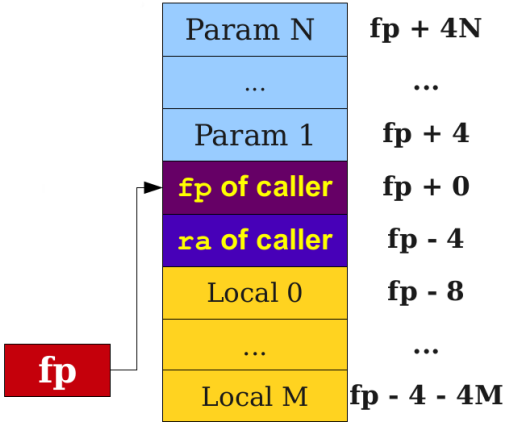


Physical Stack Frames



Gde se čuvaju vrednosti parametara

- Parametri počinju od adrese fp+4 i rastu naviše
- Lokalne promenljive i privremene promenljive počinju od adrese fp-8, i rastu naniže


Param N
fp + 4N
...
...
Param 1
fp + 4
fp of caller
fp + 0
ra of caller
fp - 4
Local 0
fp - 8
...
...
Local M
fp - 4 - 4M
fp

And One More Thing...

```
int globalVariable;

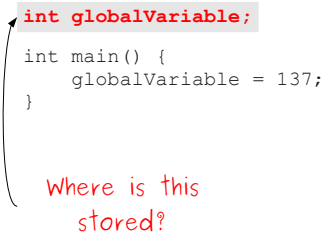
int main() {
    globalVariable = 137;
}
```

And One More Thing...

```
int globalVariable;

int main() {
    globalVariable = 137;
}
```

And One More Thing...



Global pointer

- MIPS takođe ima registar koji se naziva *golbal pointer* (gp) koji čuva adresu globalnog prostora
- Memorija na koju pokazuje globalni pointer se tretira kao niz vrednosti koji raste naviše
- Potrebno je za svaku globalnu promenljivu odrediti pomeraj u ovom nizu tj gde se ona tačno u tom nizu čuva

Rezime izgleda memorije

- Većina detalja je apstrahovana IR formatom
- Parametri počinju na adresi fp + 4 i rastu naviše
- Lokalne promenljive počinju na adresi fp - 8 i rastu naniže
- Globalne promenljive počinju od adrese gp + 0 i rastu naviše

Pregled

TAC for Objects, Part I

```
class A {
    void fn(int x) {
        int y;
        y = x;
    }
}

int main() {
    A a;
    a.fn(137);
}
```

TAC for Objects, Part I

```
class A {
    void fn(int x) {
        int y;
        y = x;
    }
}

int main() {
    A a;
    a.fn(137);
}
```

```
_A.fn:
    BeginFunc 4;
    y = x;
    EndFunc;

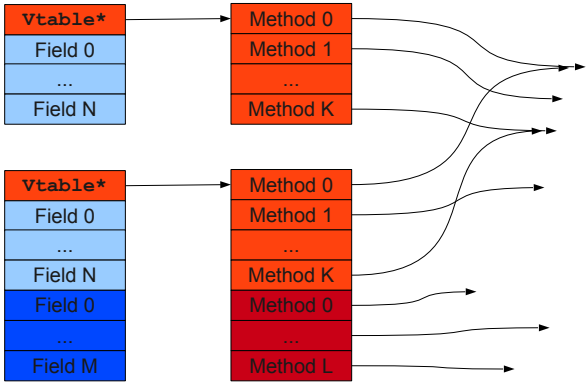
main:
    BeginFunc 8;
    _t0 = 137;
    PushParam _t0;
    PushParam a;
    LCall _A.fn;
    PopParams 8;
    EndFunc;
```

Pristup memoriji

- Potrebno je da proširimo TAC tako da ima mogućnost pristupa memoriji, tj potrebno je da pristup poljima objekta pretvorimo u relativne memorijske adrese

```
var_1 = *var_2
var_1 = *(var_2 + constant)
*var_1 = var_2
*(var_1 + constant) = var_2
```

A Reminder: Object Layout



TAC for Objects, Part II

```
class A {
    int y;
    int z;
    void fn(int x) {
        y = x;
        x = z;
    }
}

int main() {
    A a;
    a.fn(137);
}
```

TAC for Objects, Part II

```
class A {
    int y;
    int z;
    void fn(int x) {
        y = x;
        x = z;
    }
}

int main() {
    A a;
    a.fn(137);
}
```

```
_A.fn:
    BeginFunc 4;
    *(this + 4) = x;
    x = *(this + 8);
    EndFunc;

main:
    BeginFunc 8;
    _t0 = 137;
    PushParam _t0;
    PushParam a;
    LCall _A.fn;
    PopParams 8;
    EndFunc;
```

TAC for Objects, Part II

```
class A {
    int y;
    int z;
    void fn(int x) {
        y = x;
        x = z;
    }
}

int main() {
    A a;
    a.fn(137);
}
```

```
_A.fn:
    BeginFunc 4;
    *(this + 4) = x;
    x = *(this + 8);
    EndFunc;

main:
    BeginFunc 8;
    _t0 = 137;
    PushParam _t0;
    PushParam a;
    LCall _A.fn;
    PopParams 8;
    EndFunc;
```

TAC for Objects, Part II

```
class A {
    int y;
    int z;
    void fn(int x) {
        y = x;
        x = z;
    }
}

int main() {
    A a;
    a.fn(137);
}
```

```
_A.fn:
    BeginFunc 4;
    *(this + 4) = x;
    x = *(this + 8);
    EndFunc;

main:
    BeginFunc 8;
    _t0 = 137;
    PushParam _t0;
    PushParam a;
    LCall _A.fn;
    PopParams 8;
    EndFunc;
```

OOP in TAC

- Kako obezbediti dinamičko razrešavanje poziva metoda?
- Adresa virtuelne tabele objekta može da se referencira kroz ime dodeljeno virtuelnoj tabeli, obično je to ime isto kao ime objekta, npr `_t0 = Base;`
- Kada se kreira objekat, mora prvo da se postavi pokazivač na virtuelnu tabelu
- Instrukcija `ACall` može da se koristi za poziv metoda kada je za njega dat pokazivač na prvu instrukciju

TAC for Objects, Part III

```
class Base {
  void hi() {
    Print("Base");
  }
}

class Derived extends Base{
  void hi() {
    Print("Derived");
  }
}

int main() {
    Base b;
    b = new Derived;
    b.hi();
}
```

TAC for Objects, Part III

```
class Base {
  void hi() {
    Print("Base");
  }
}

class Derived extends Base{
  void hi() {
    Print("Derived");
  }
}

int main() {
    Base b;
    b = new Derived;
    b.hi();
}
```

TAC for Objects, Part III

```
class Base {
  void hi() {
    Print("Base");
  }
}

class Derived extends Base{
  void hi() {
    Print("Derived");
  }
}

int main() {
    Base b;
    b = new Derived;
    b.hi();
}
```

```
_Base.hi:
    BeginFunc 4;
    _t0 = "Base";
    PushParam _t0;
    LCall _PrintString;
    PopParams 4;
    EndFunc;
Vtable Base = _Base.hi,
    ;

_Derived.hi:
    BeginFunc 4;
    _t0 = "Derived";
    PushParam _t0;
    LCall _PrintString;
    PopParams 4;
    EndFunc;
Vtable Derived = _Derived.hi,
    ;
```

TAC for Objects, Part III

```
class Base {
  void hi() {
    Print("Base");
  }
}

class Derived extends Base{
  void hi() {
    Print("Derived");
  }
}

int main() {
    Base b;
    b = new Derived;
    b.hi();
}
```

```
_Base.hi:
    BeginFunc 4;
    _t0 = "Base";
    PushParam _t0;
    LCall _PrintString;
    PopParams 4;
    EndFunc;
Vtable Base = _Base.hi,
    ;

_Derived.hi:
    BeginFunc 4;
    _t0 = "Derived";
    PushParam _t0;
    LCall _PrintString;
    PopParams 4;
    EndFunc;
Vtable Derived = _Derived.hi,
    ;
```

TAC for Objects, Part III

```
class Base {
  void hi() {
    Print("Base");
  }
}

class Derived extends Base{
  void hi() {
    Print("Derived");
  }
}

int main() {
    Base b;
    b = new Derived;
    b.hi();
}
```

```
_Base.hi:
    BeginFunc 4;
    _t0 = "Base";
    PushParam _t0;
    LCall _PrintString;
    PopParams 4;
    EndFunc;
Vtable Base = _Base.hi,
    ;

_Derived.hi:
    BeginFunc 4;
    _t0 = "Derived";
    PushParam _t0;
    LCall _PrintString;
    PopParams 4;
    EndFunc;
Vtable Derived = _Derived.hi,
    ;
```

TAC for Objects, Part III

```
class Base {
  void hi() {
    Print("Base");
  }
}

class Derived extends Base{
  void hi() {
    Print("Derived");
  }
}

int main() {
    Base b;
    b = new Derived;
    b.hi();
}
```

```
main:
    BeginFunc 20;
    _t0 = 4;
    PushParam _t0;
    b = LCall _Alloc;
    PopParams 4;
    _t1 = Derived;
    *b = _t1;
    _t2 = *b;
    _t3 = *_t2;
    PushParam b;
    ACall _t3;
    PopParams 4;
    EndFunc;
```

TAC for Objects, Part III

```
class Base {
  void hi() {
    Print("Base");
  }
}

class Derived extends Base{
  void hi() {
    Print("Derived");
  }
}

int main() {
    Base b;
    b = new Derived;
    b.hi();
}
```

```
main:
    BeginFunc 20;
    _t0 = 4;
    PushParam _t0;
    b = LCall _Alloc;
    PopParams 4;
    _t1 = Derived;
    *b = _t1;
    _t2 = *b;
    _t3 = *_t2;
    PushParam b;
    ACall _t3;
    PopParams 4;
    EndFunc;
```

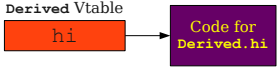
What's going on here?

Dissecting TAC

```
int main() {
    Base b;
    b = new Derived;
    b.hi();
}
```

```
main:
    BeginFunc 20;
    _t0 = 4;
    PushParam _t0;
    b = LCall _Alloc;
    PopParams 4;
    _t1 = Derived;
    *b = _t1;
    _t2 = *b;
    _t3 = *_t2;
    PushParam b;
    ACall _t3;
    PopParams 4;
    EndFunc;
```

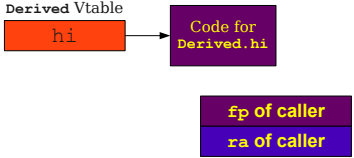
Dissecting TAC




```
int main() {
    Base b;
    b = new Derived;
    b.hi();
}
```

```
main:
    BeginFunc 20;
    _t0 = 4;
    PushParam _t0;
    b = LCall _Alloc;
    PopParams 4;
    _t1 = Derived;
    *b = _t1;
    _t2 = *b;
    _t3 = *_t2;
    PushParam b;
    ACall _t3;
    PopParams 4;
    EndFunc;
```

Dissecting TAC




```
int main() {
    Base b;
    b = new Derived;
    b.hi();
}
```

```
main:
    BeginFunc 20;
    _t0 = 4;
    PushParam _t0;
    b = LCall _Alloc;
    PopParams 4;
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    *b = _t1;
    _t2 = *b;
    _t3 = *_t2;
    PushParam b;
    ACall _t3;
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    EndFunc;
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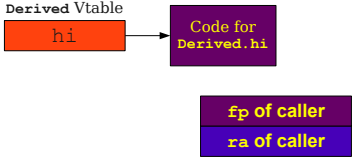
Dissecting TAC

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    b = new Derived;
    b.hi();
}
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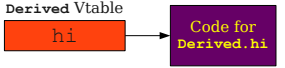

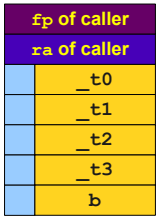


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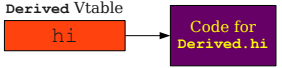

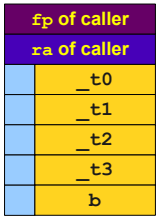


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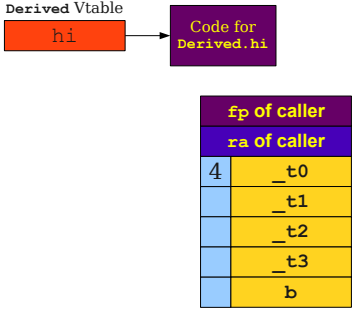


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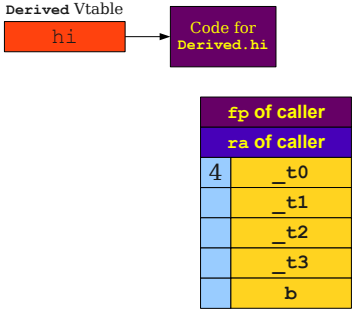


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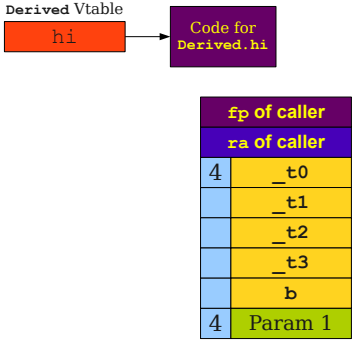


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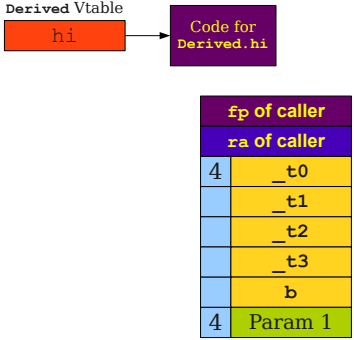


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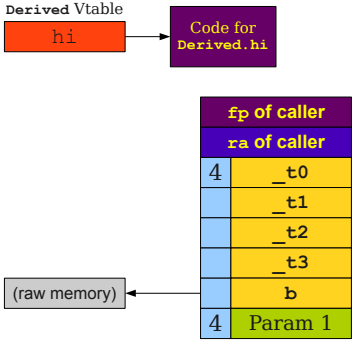


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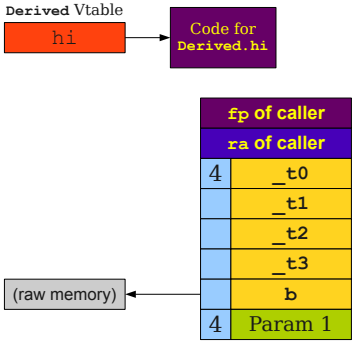
Dissecting TAC

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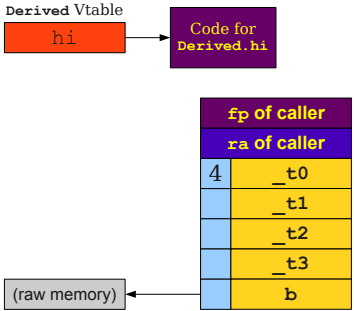


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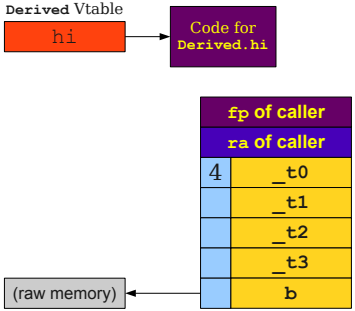


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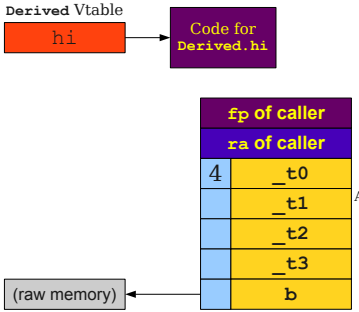


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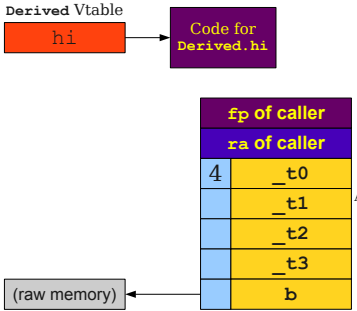
Dissecting TAC

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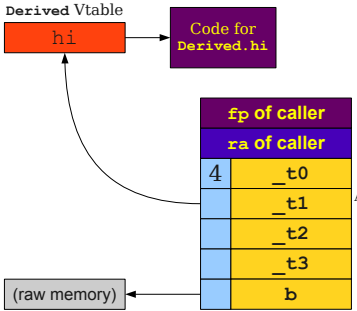
Allocate Object

Dissecting TAC

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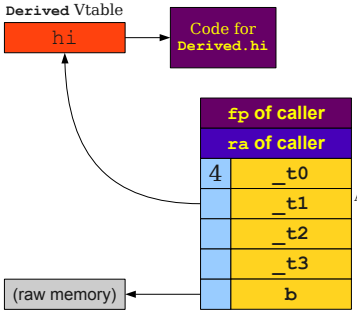
Allocate Object

Dissecting TAC

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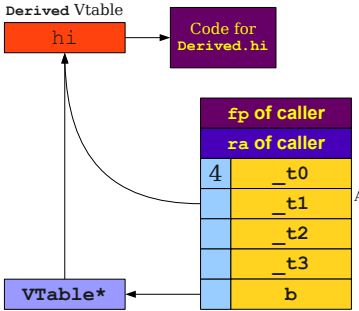


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Allocate Object

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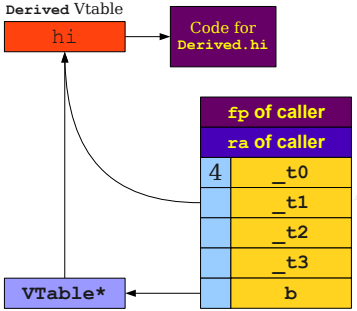


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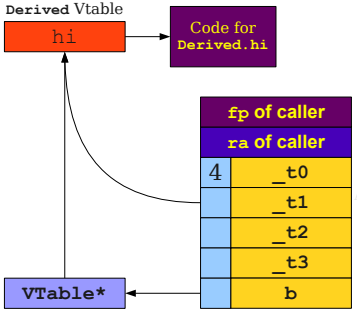


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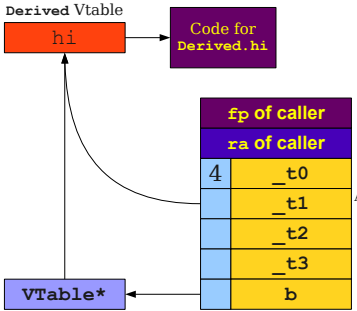
Allocate Object

Set Vtable

Dissecting TAC

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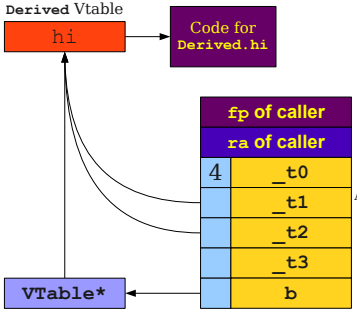
Allocate Object

Set Vtable

Dissecting TAC

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Set Vtable

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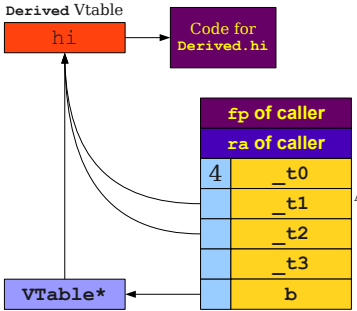


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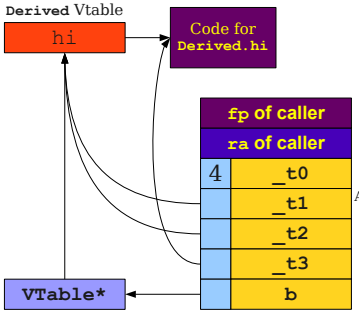
Allocate Object

Set Vtable

Dissecting TAC

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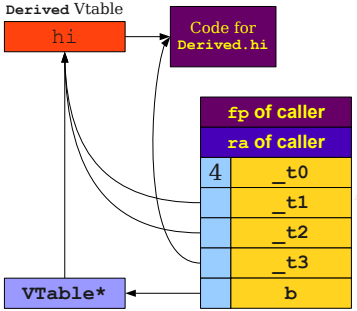
Allocate Object

Set Vtable

Dissecting TAC

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Set Vtable

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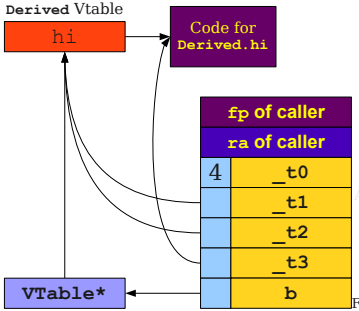


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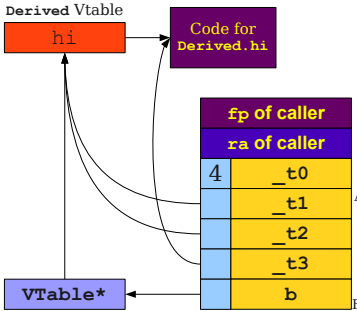
```

Allocate Object

Set Vtable

Load Function

Dissecting TAC




```
int main() {
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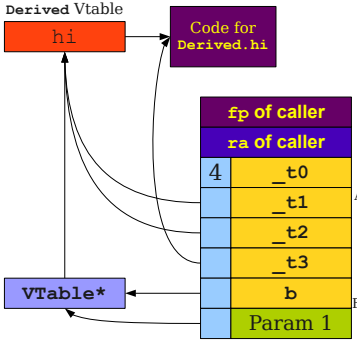
    b.hi();
}
```

```
main:
    BeginFunc 20;
    _t0 = 4;                    // Allocate Object
    PushParam _t0;
    b = LCall _Alloc;
    PopParams 4;
    _t1 = Derived;              // Set Vtable
    *b = _t1;
    _t2 = *b;                   // Load Function
    _t3 = *_t2;
    PushParam b;
    ACall _t3;
    PopParams 4;
    EndFunc;
```

Dissecting TAC

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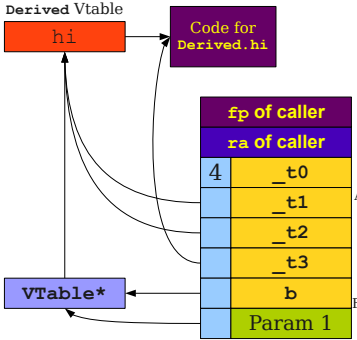
```

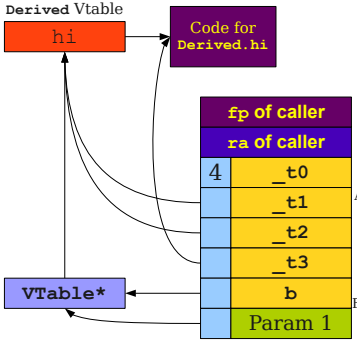
Dissecting TAC




```
int main() {
    Base b;
    b = new Derived;
    b.hi();
}
```

```
main:
    BeginFunc 20;
    _t0 = 4;                  // Allocate Object
    PushParam _t0;
    b = LCall _Alloc;
    PopParams 4;
    _t1 = Derived;            // Set Vtable
    *b = _t1;
    _t2 = *b;                 // Load Function
    _t3 = *_t2;
    PushParam b;
    ACall _t3;
    PopParams 4;
    EndFunc;
```

Dissecting TAC

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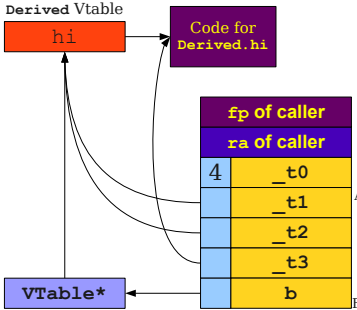
Dissecting TAC

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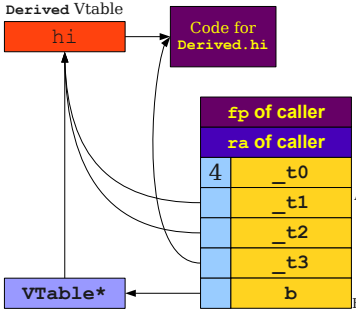
Dissecting TAC

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    _t2 = *b;                   // Load Function
    _t3 = *_t2;
    PushParam b;
    ACall _t3;
    PopParams 4;
    EndFunc;
```

Pregled

Generisanje troadresnog koda

- U ovom stadijumu kompilacije, imamo na raspolaganju
  - AST
  - koji je anotiran sa informacijama o dosegu
  - koji je anotiran i sa informacijama o tipovima
- Da bi se generisao TAC, potrebno je još jednom obići rekruzivno AST
  - Generiši TAC za svaki podizraz ili podnaredbu
  - Koristeći generisani TAC za podizraze/naredbe, generiši TAC za kompletne izraze i naredbe

Generisanje TACa za izraze

- Definiši funkciju `cgen(expr)` koja generiše TAC koji računa izraz, čuva generisanu vrednost u privremenoj promenljivoj i vraća ime te promenljive
  - Definiši `cgen(expr)` direktno za atomičke izraze (konstante, this, identifikatore i slično)
  - Definiši `cgen(expr)` rekurzivno za složene izraze (binarne operatore, pozive funkcija)

cgen for Basic Expressions

cgen for Basic Expressions

cgen(k) = { // k is a constant
    Choose a new temporary t
    Emit($t = k$);
    Return t
}

cgen for Basic Expressions

cgen(k) = { // k is a constant
    Choose a new temporary t
    Emit($t = k$);
    Return t
}

cgen(id) = { // id is an identifier
    Choose a new temporary t
    Emit($t = id$)
    Return t
}

cgen for Binary Operators

cgen for Binary Operators

cgen(e_1 + e_2) = {
    Choose a new temporary t
    Let t_1 = **cgen**(e_1)
    Let t_2 = **cgen**(e_2)
    Emit($t = t_1 + t_2$)
    Return t
}

An Example

cgen(5 + x) = {
    Choose a new temporary t
    Let t_1 = **cgen**(5)
    Let t_2 = **cgen**(x)
    Emit ($t = t_1 + t_2$)
    Return t
}

An Example

cgen(5 + x) = {
    Choose a new temporary t
    Let t_1 = {
        Choose a new temporary t
        Emit(t = 5)
        return t
    }
    Let t_2 = **cgen**(x)
    Emit ($t = t_1 + t_2$)
    Return t
}

An Example

cgen(5 + x) = {
    Choose a new temporary *t*
    Let t_1 = {
        Choose a new temporary *t*
        Emit(*t* = 5)
        return *t*
    }
    Let t_2 = {
        Choose a new temporary *t*
        Emit(*t* = x)
        return *t*
    }
    Emit (t = t_1 + t_2)
    Return t
}

An Example

cgen(5 + x) = {
  Choose a new temporary *t*
  Let t_1 = {
    Choose a new temporary *t*
    Emit(*t* = 5)
    return *t*
  }
  Let t_2 = {
    Choose a new temporary *t*
    Emit(*t* = x)
    return *t*
  }
  Emit (*t* = t_1 + t_2)
  Return t
}

```
_t0 = 5
_t1 = x
_t2 = _t0 + _t1
```

Generisanje izraza

- Za vežbu definišite cgen
  - za druge binarne operatore,
  - za unarni operator -,
  - za ternarni operator ?
  - ...
- Pogledajte kako se složeni izraz pretvara u TAC sa ovim algoritmom
- Ako niste sigurni kako neki TAC treba da izgleda, uvek možete da pogledate LLVM IR za odgovarajući C kod (samo vodite računa da isključite optimizacije prilikom generisanja IRa)

Generisanje naredbi

- Možemo proširiti funkciju cgen tako da radi sa naredbama
- Za razliku od cgen za izraze, cgen za naredbe ne vraća ime privremene promenljive koja čuva vrednost

cgen for Simple Statements

cgen for Simple Statements

cgen(*expr*;) = {
    cgen(*expr*)
}

cgen for `while` loops

cgen for `while` loops

cgen(`while (`*expr*`)` *stmt*) = {

}

cgen for `while` loops

cgen(`while (`*expr*`)` *stmt*) = {
Let L_{before} be a new label.
Let L_{after} be a new label.

}

cgen for `while` loops

cgen(`while (`*expr*`)` *stmt*) = {

Let L_{before} be a new label.

Let L_{after} be a new label.

Emit(L_{before}`:`)

Emit(L_{after}`:`)

}

cgen for `while` loops

cgen(`while (`*expr*`)` *stmt*) = {

Let L_{before} be a new label.

Let L_{after} be a new label.

Emit(L_{before}`:`)

Let t = **cgen**(*expr*)

Emit(`IfZ` t `Goto` L_{after})

Emit(L_{after}`:`)

}

cgen for `while` loops

cgen(`while (`*expr*`)` *stmt*) = {

Let L_{before} be a new label.

Let L_{after} be a new label.

Emit(L_{before}`:`)

Let t = **cgen**(*expr*)

Emit(`IfZ` t `Goto` L_{after})

cgen(*stmt*)

Emit(L_{after}`:`)

}

cgen for `while` loops

cgen(`while (`*expr*`)` *stmt*) = {
Let L_{before} be a new label.
Let L_{after} be a new label.
Emit(L_{before}`:`)
Let t = **cgen**(*expr*)
Emit(`IfZ` t `Goto` L_{after})
cgen(*stmt*)
Emit(`Goto` L_{before})
Emit(L_{after}`:`)
}

Generisanje naredbi

- Za vežbu definišite `cgen`
  - za naredbu `if`
  - za naredbu `for`
  - za naredbu `do-while`
  - za naredbu `break`
  - za naredbu `continue`
  - ...
- Ako niste sigurni kako neki TAC treba da izgleda, uvek možete da pogledate LLVM IR za odgovarajući C kod (samo vodite računa da isključite optimizacije prilikom generisanja IRa)

Pregled

Literatura

- (The Dragon Book) Compilers: Principles, Techniques, and Tools Alfred V. Aho,Monica S. Lam, Ravi Sethi, and Jeffrey D. Ullman
- Kompajleri Stanford
  `https://web.stanford.edu/class/archive/cs/cs143/cs143.1128/`