

Konstrukcija kompilatora

— Troadresni kod —

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Pregled

- 1 Troadresni kod
- 2 Troadresni kod za objekte
- 3 Generisanje troadresnog koda
- 4 Literatura

Pregled

- 1 Troadresni kod
 - Aritmetičke i bulovske operacije
 - Kontrola toka
 - Funkcije i stek okviri
 - Dodatne informacije u stek okviru
- 2 Troadresni kod za objekte
- 3 Generisanje troadresnog koda
- 4 Literatura

Troadresni kod

- Troadresni kod - međurepresentacija 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 redundantna 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 proizvoljen 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 `bools`

```
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 `bools`

```
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 $b = (x \leq y)$?

TAC sa bool vrednostima

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- Pored aritmetičkih operatora, podržavamo i $<$, $==$, $||$ i $&&$
- Kako bi moglo da se prevede $b = (x \leq y)$?

```
_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;  
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if (x < y)  
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    _t0 = x < y;  
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_L0:  
    z = y;  
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    z = z * z;
```

Control Flow Statements

```
int x;  
int y;  
int z;  
  
if (x < y)  
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    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 N`; koja rezerviše `N` 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

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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;  
    }  
}
```

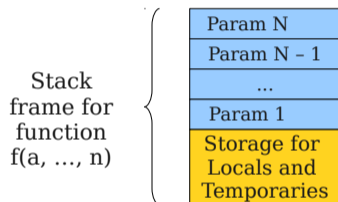
```
main:  
    BeginFunc 24;  
    _t0 = x * x;  
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    m2 = _t0 + _t1;  
_L0:  
    _t2 = 5 < m2;  
    IfZ _t2 Goto _L1;  
    m2 = m2 - x;  
    Goto _L0;  
_L1:  
    EndFunc;
```


Upravljanje stekom u TACu

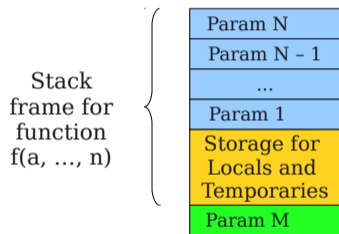
Podsetnik:

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

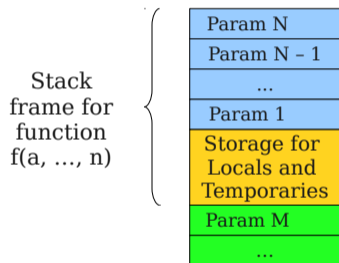
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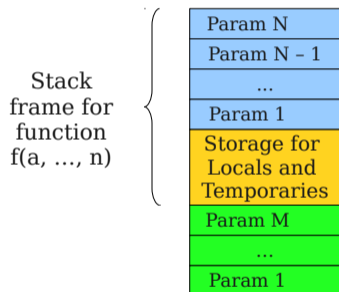
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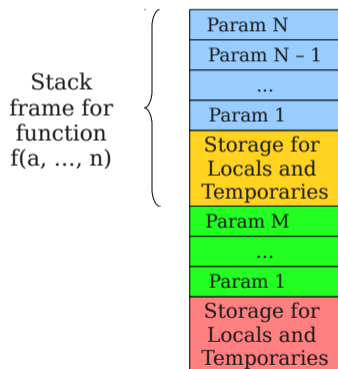
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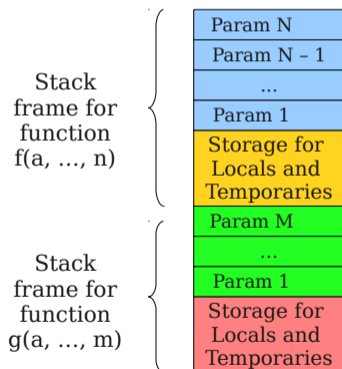
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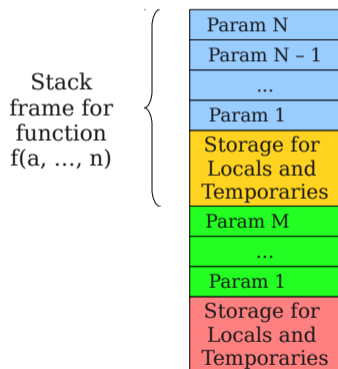
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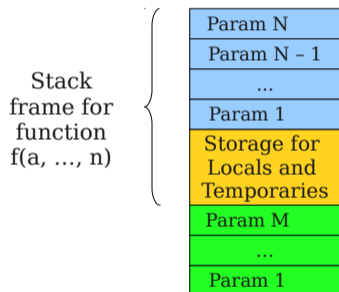
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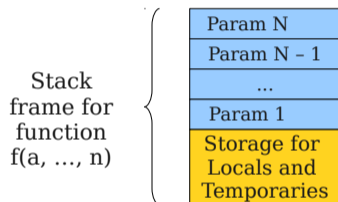
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A Logical Decaf Stack Frame



Upravljanje stekom u TACu

- Instrukcija `BeginFunc N`; rezerviše prostor za lokalne i privremene promenljive
- Instrukcija `EndFunc`; vraća prostor koji je rezervisan sa `BeginFunc N`;
- Jedna parametar je gurnut na stek od strane pozivaoca korišćenjem instrukcije `PushParam var`
- Prostor je oslobođen od strane pozivaoca korišćenjem instrukcije `PopParams N`;
- `N` se meri u bajtovima, ne po broju argumenata!

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

```
void SimpleFn(int z) {  
    int x, y;  
    x = x * y * z;  
}  
  
void main() {  
    SimpleFunction(137);  
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Compiling Function Calls

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    int x, y;  
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}  
  
void main() {  
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```

```
_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);  
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```
_SimpleFn:  
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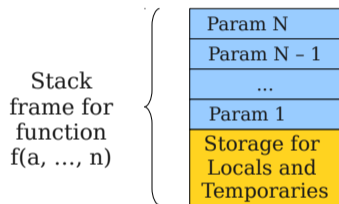
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```

Compiling Function Calls

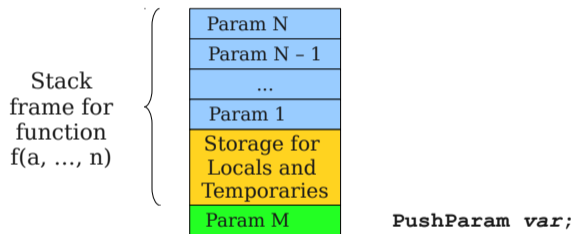
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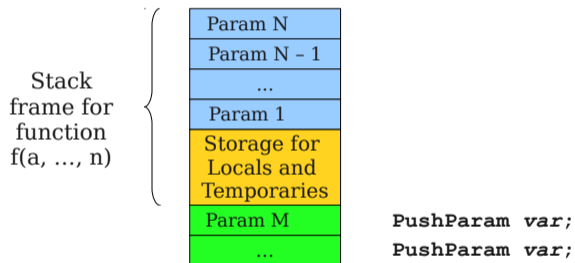
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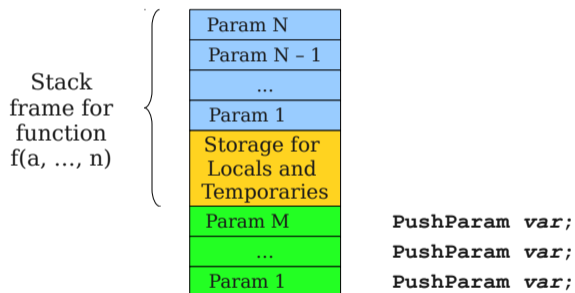
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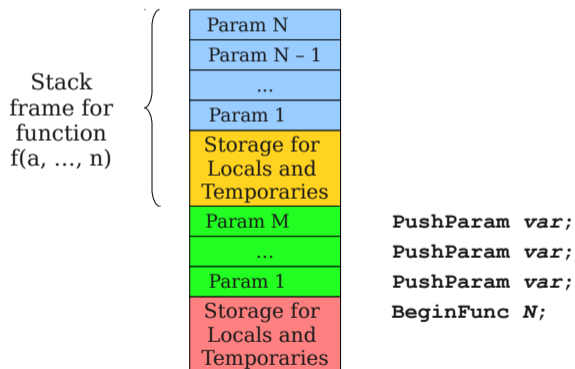
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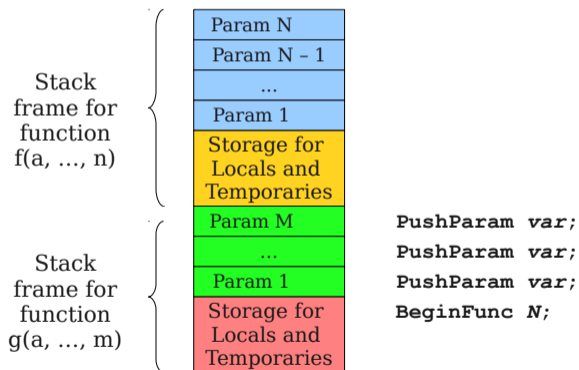
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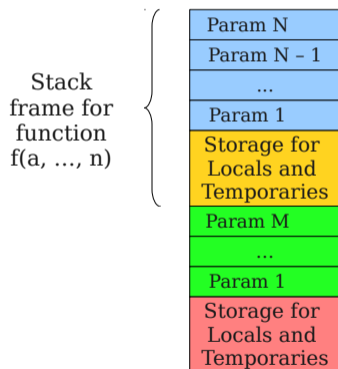
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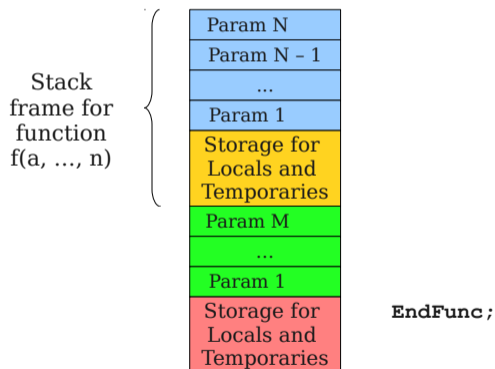
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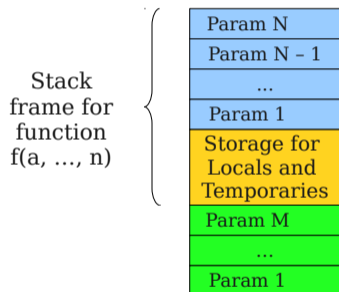
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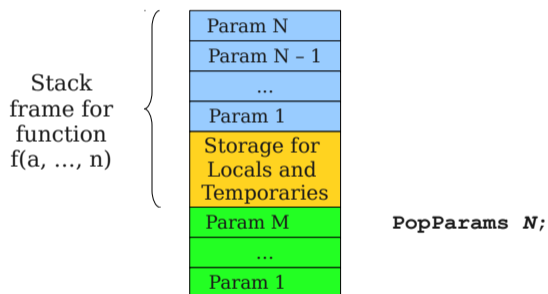
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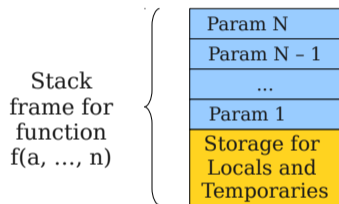
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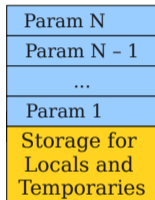
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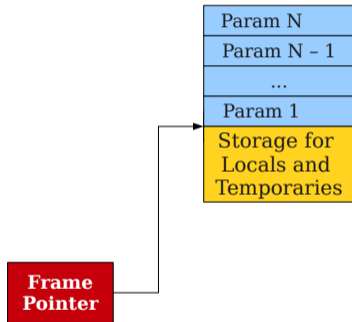
Frame pointer

- 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

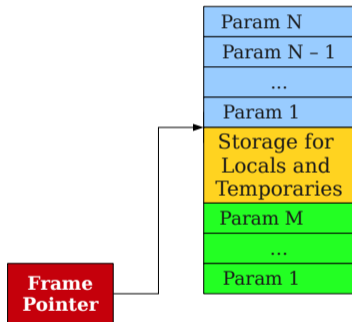
The Frame Pointer



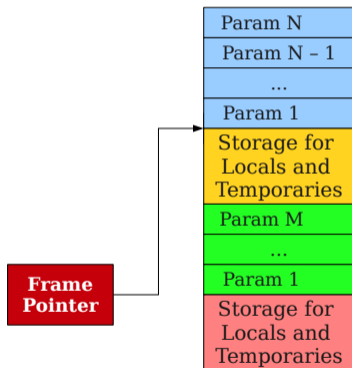
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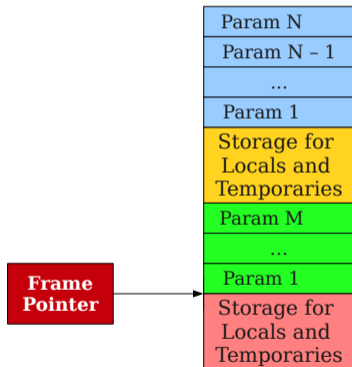
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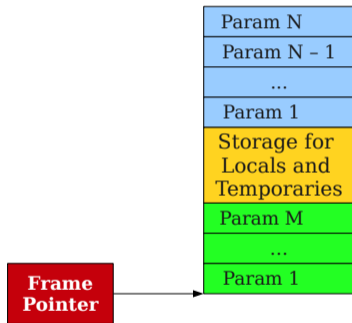
The Frame Pointer



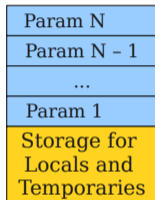
The Frame Pointer



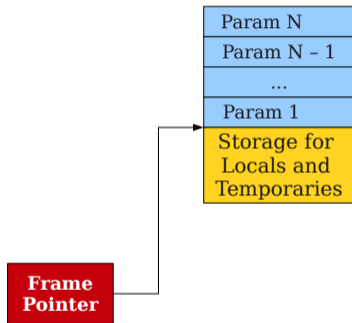
The Frame Pointer



The Frame Pointer



The Frame Pointer



Logical vs Physical Stack Frames

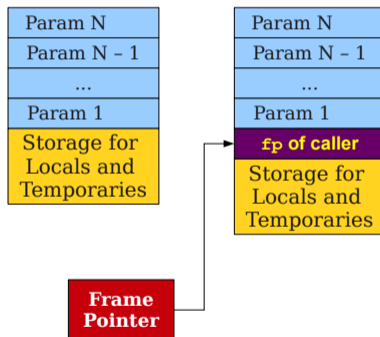
Param N
Param N - 1
...
Param 1
Storage for Locals and Temporaries

Logical vs Physical Stack Frames

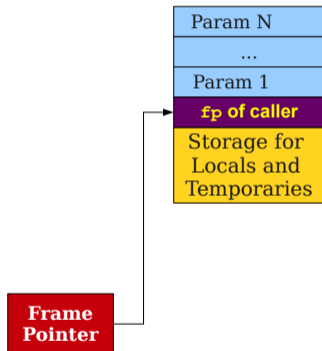
Param N
Param N - 1
...
Param 1
Storage for Locals and Temporaries

Param N
Param N - 1
...
Param 1
fp of caller
Storage for Locals and Temporaries

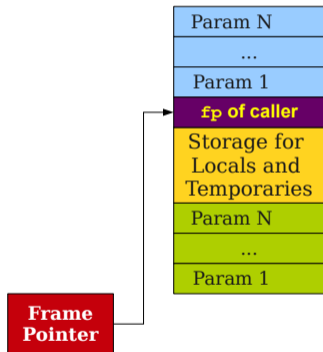
Logical vs Physical Stack Frames



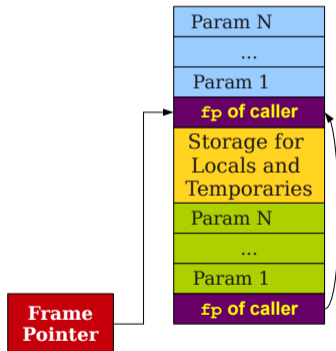
(Mostly) Physical Stack Frames



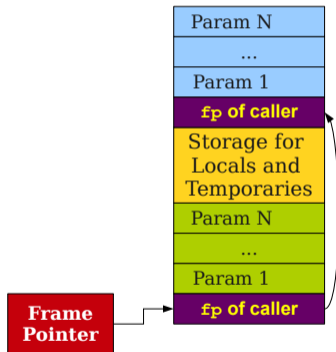
(Mostly) Physical Stack Frames



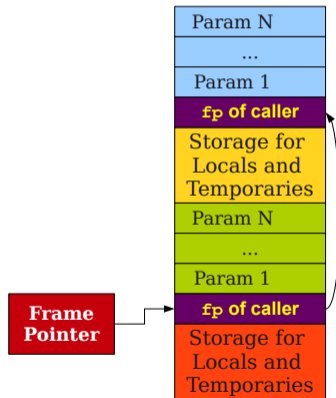
(Mostly) Physical Stack Frames



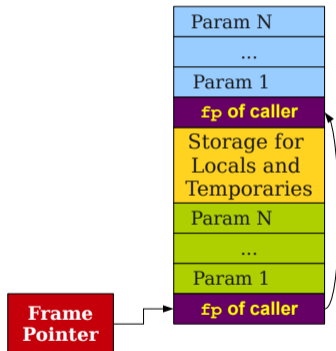
(Mostly) Physical Stack Frames



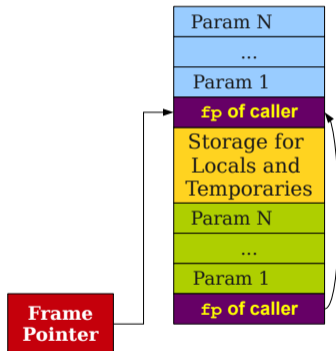
(Mostly) Physical Stack Frames



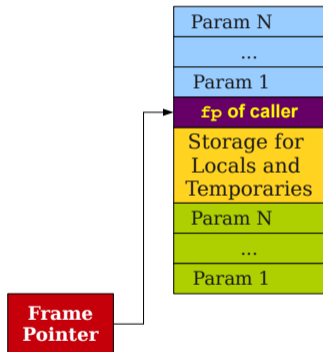
(Mostly) Physical Stack Frames



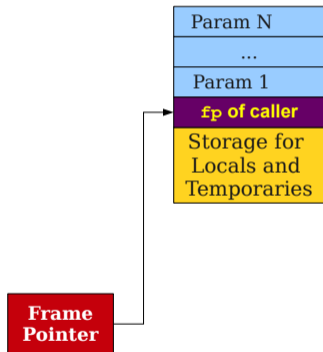
(Mostly) Physical Stack Frames



(Mostly) Physical Stack Frames



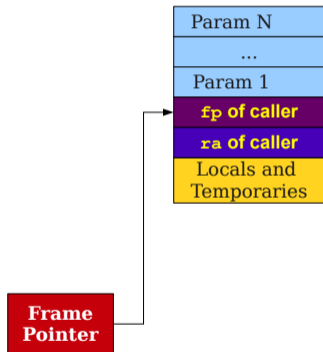
(Mostly) Physical Stack Frames



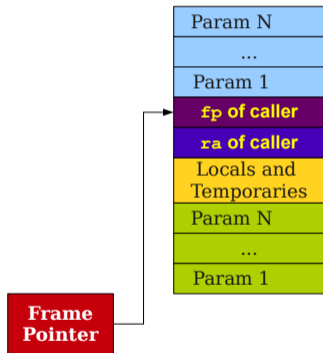
Dodatne informacije u stek okviru

- 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*

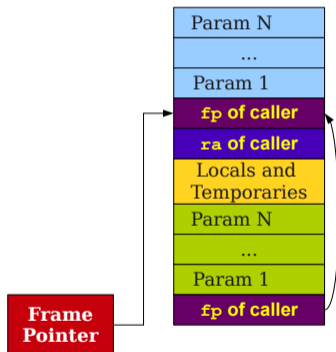
Physical Stack Frames



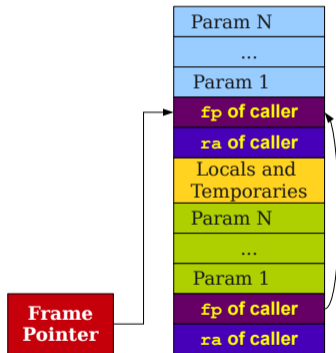
Physical Stack Frames



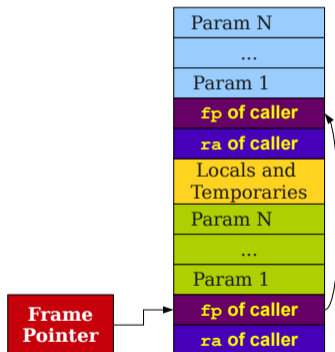
Physical Stack Frames



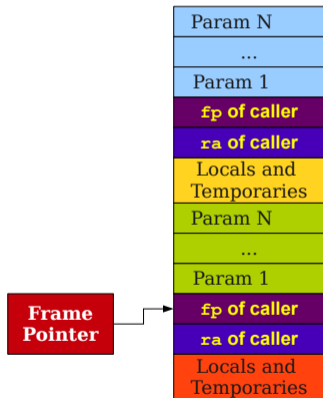
Physical Stack Frames



Physical Stack Frames

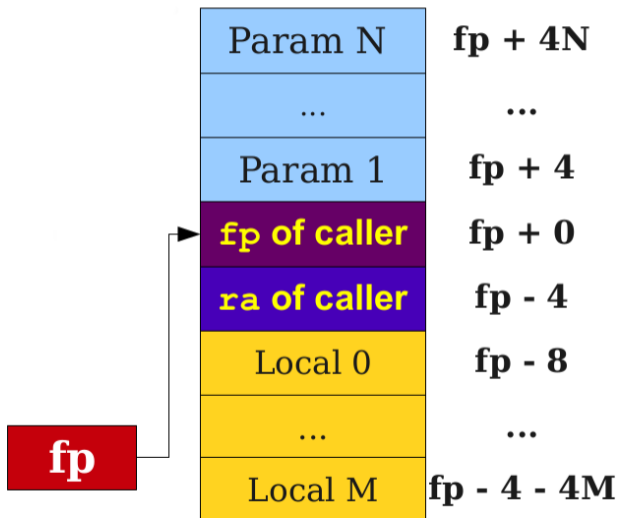


Physical Stack Frames



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



And One More Thing...

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

And One More Thing...

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

And One More Thing...

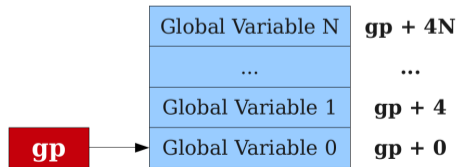
```
int globalVariable;
```

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

Where is this
stored?

Global pointer

- MIPS takođe ima registar koji se naziva *global 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

- 1 Troadresni kod
- 2 Troadresni kod za objekte
 - Poziv metoda
 - Pristup podacima
 - Dinamičko razrešavanje poziva
- 3 Generisanje troadresnog koda
- 4 Literatura

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

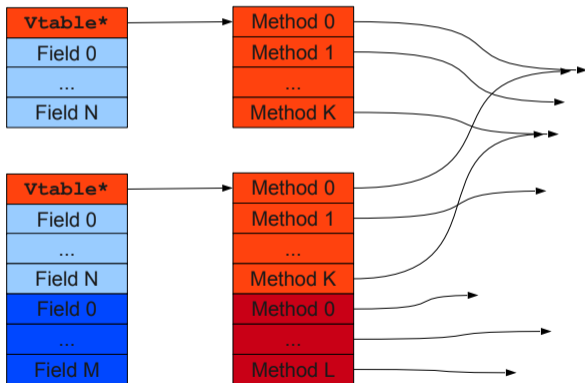
```
var_1 = *var_2
```

```
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;
```

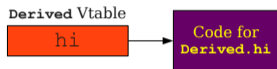
What's going
on here?

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

Derived Vtable

hi

Code for
Derived.hi

fp of caller

ra of caller

```
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

Derived Vtable

hi

Code for
Derived.hi

fp of caller

ra of caller

```
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

Derived Vtable

hi

Code for
Derived.hi

fp of caller	
ra of caller	
	_t0
	_t1
	_t2
	_t3
	b

```
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

Derived Vtable

hi

Code for
Derived.hi

fp of caller	
ra of caller	
	_t0
	_t1
	_t2
	_t3
	b

```
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

Derived Vtable

hi

Code for
Derived.hi

fp of caller	
ra of caller	
4	_t0
	_t1
	_t2
	_t3
	b

```
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

Derived Vtable

hi

Code for
Derived.hi

fp of caller	
ra of caller	
4	_t0
	_t1
	_t2
	_t3
	b

```
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

Derived Vtable

hi

Code for
Derived.hi

fp of caller	
ra of caller	
4	_t0
	_t1
	_t2
	_t3
	b
4	Param 1

```
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

Derived Vtable

hi

Code for
Derived.hi

fp of caller	
ra of caller	
4	_t0
	_t1
	_t2
	_t3
	b
4	Param 1

```
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

Derived Vtable

hi

Code for
Derived.hi

fp of caller

ra of caller

4	_t0
	_t1
	_t2
	_t3
	b
4	Param 1

(raw memory)

```
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

Derived Vtable

hi

Code for
Derived.hi

fp of caller

ra of caller

4	_t0
	_t1
	_t2
	_t3
	b
4	Param 1

(raw memory)

```
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

Derived Vtable

hi

Code for
Derived.hi

fp of caller

ra of caller

4	_t0
	_t1
	_t2
	_t3
	b

(raw memory)

```
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

Derived Vtable

hi

Code for
Derived.hi

fp of caller

ra of caller

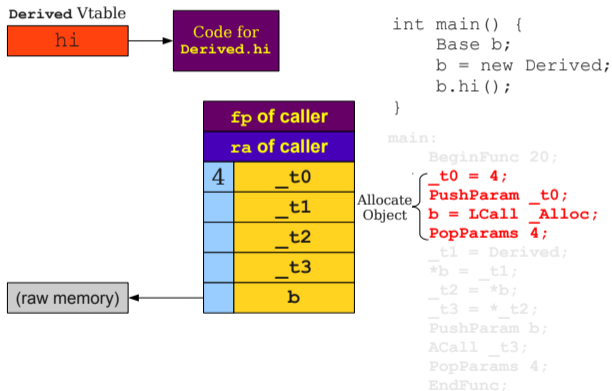
4	_t0
	_t1
	_t2
	_t3
	b

(raw memory)

```
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



Dissecting TAC

Derived Vtable

hi

Code for
Derived.hi

fp of caller

ra of caller

4	_t0
	_t1
	_t2
	_t3
	b

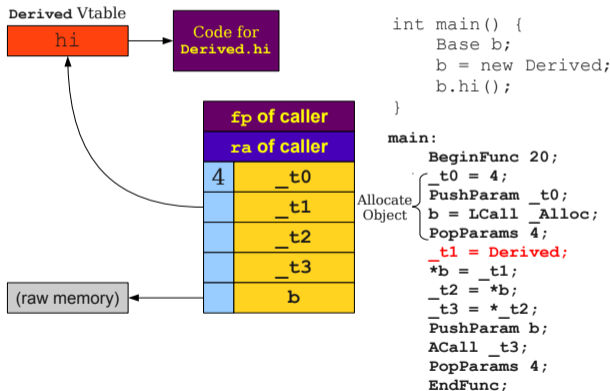
(raw memory)

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

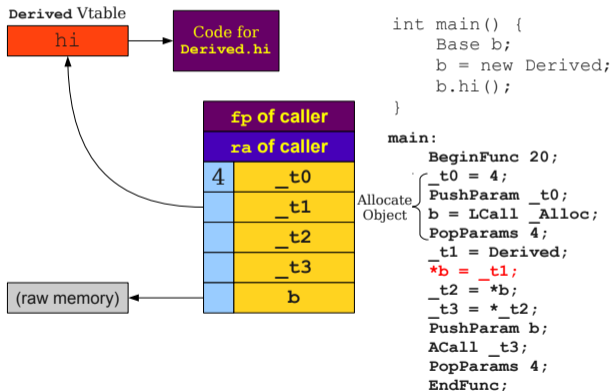
```
main:  
    BeginFunc 20;  
    _t0 = 4;  
    PushParam _t0;  
    b = LCall _Alloc;  
    PopParams 4;  
    _t1 = Derived;  
    *b = _t1;  
    _t2 = *b;  
    _t3 = *_t2;  
    PushParam b;  
    ACall _t3;  
    PopParams 4;  
    EndFunc;
```

Allocate
Object

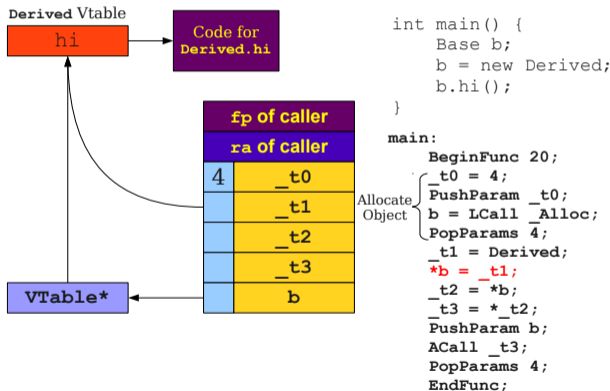
Dissecting TAC



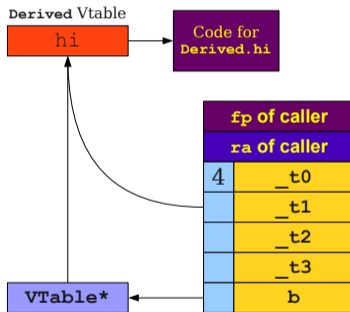
Dissecting TAC



Dissecting TAC

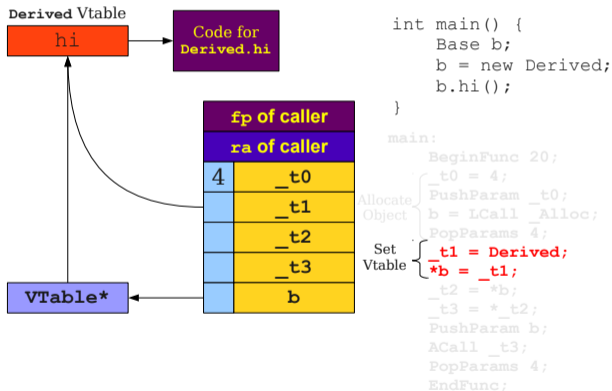


Dissecting TAC

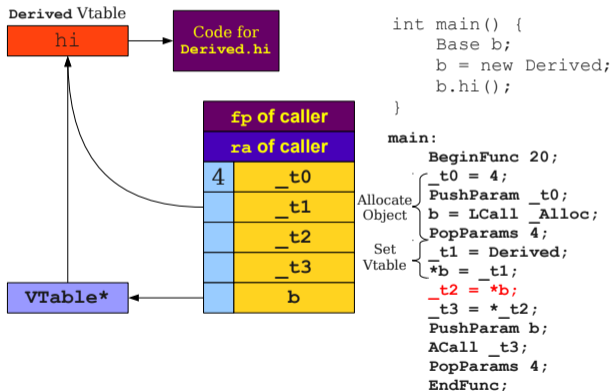


```
int main() {  
    Base b;  
    b = new Derived;  
    b.hi();  
}  
  
main:  
    BeginFunc 20;  
    _t0 = 4;  
    PushParam _t0;  
    b = LCall _Alloc;  
    PopParams 4;  
    _t1 = Derived;  
    *b = _t1;  
    _t2 = *b;  
    _t3 = *_t2;  
    PushParam b;  
    ACall _t3;  
    PopParams 4;  
    EndFunc;
```

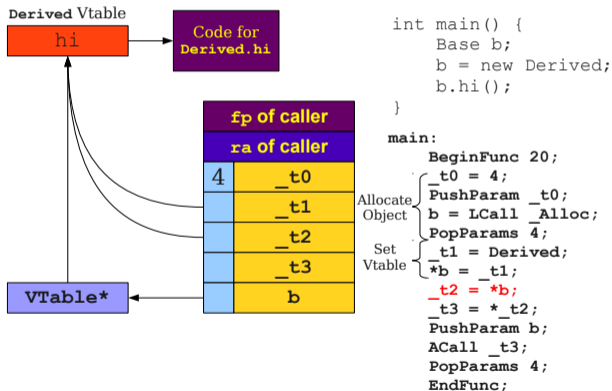
Dissecting TAC



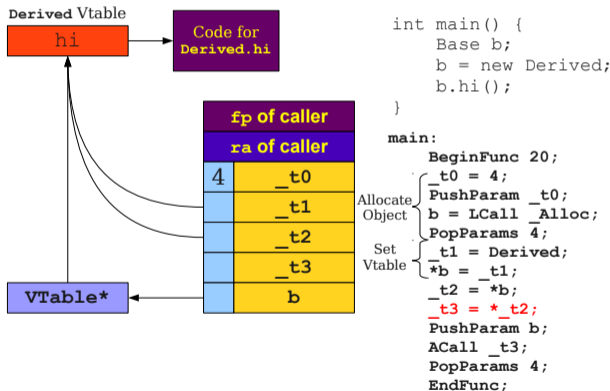
Dissecting TAC



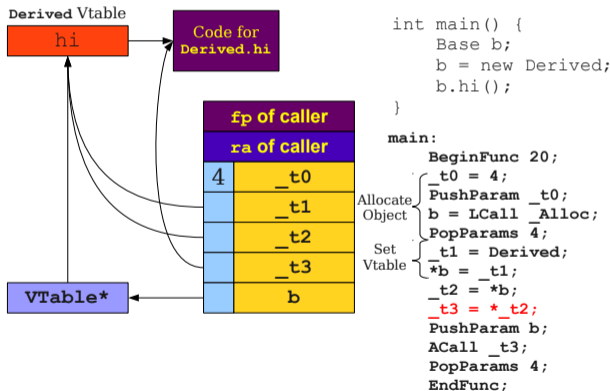
Dissecting TAC



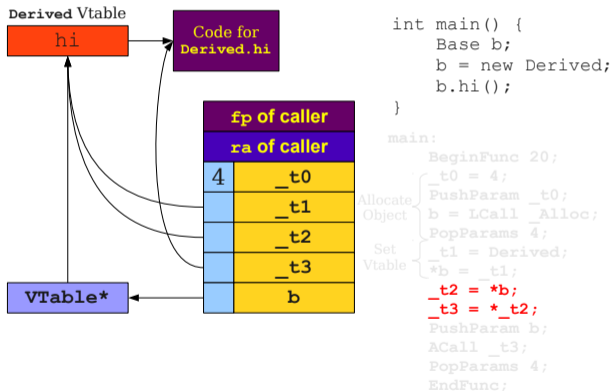
Dissecting TAC



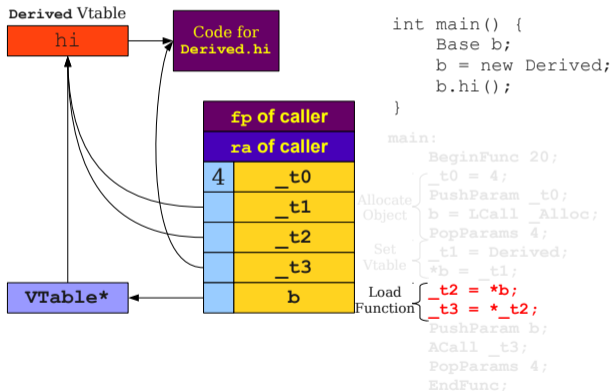
Dissecting TAC



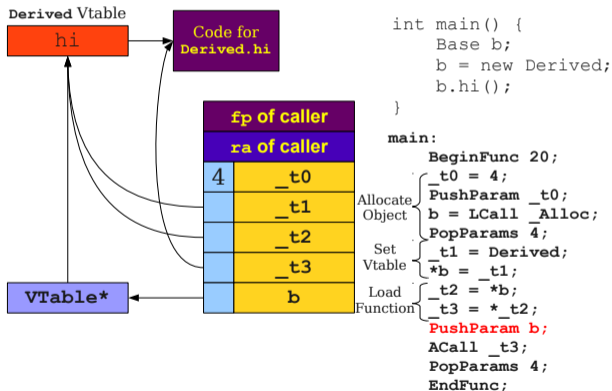
Dissecting TAC



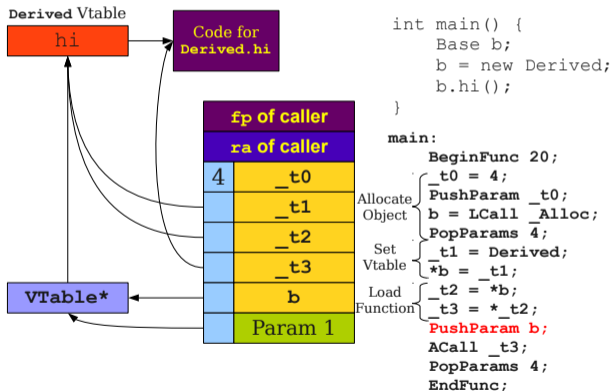
Dissecting TAC



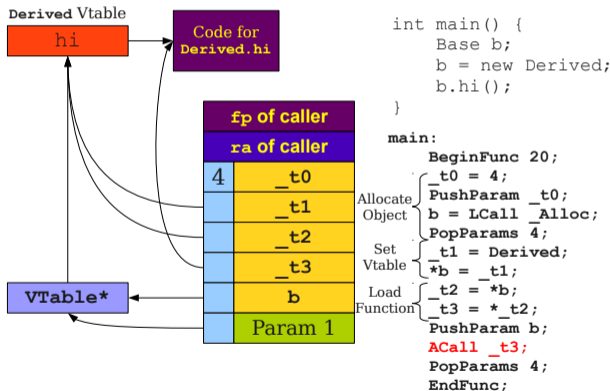
Dissecting TAC



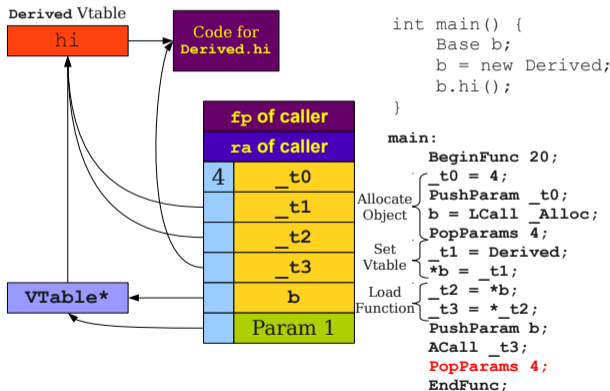
Dissecting TAC



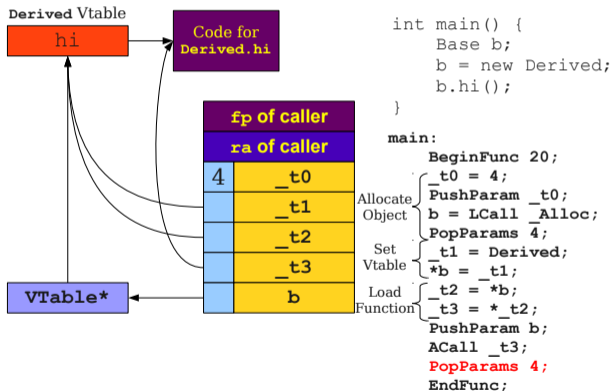
Dissecting TAC



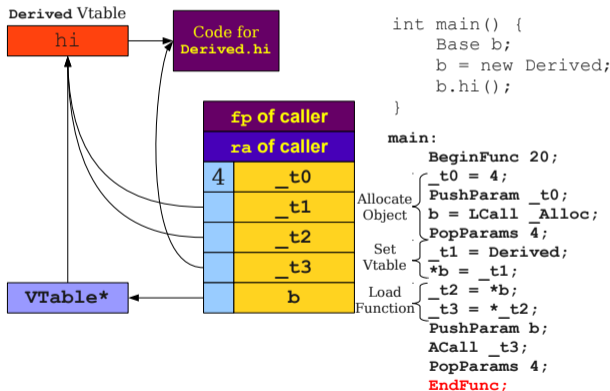
Dissecting TAC



Dissecting TAC



Dissecting TAC



Pregled

- 1 Troadresni kod
- 2 Troadresni kod za objekte
- 3 **Generisanje troadresnog koda**
 - Generisanje TACa za izraze
 - Generisanje TACa za naredbe
- 4 Literatura

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 njenu 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  $t_1 = \mathbf{cgen}(e_1)$   
    Let  $t_2 = \mathbf{cgen}(e_2)$   
    Emit(  $t = t_1 + t_2$  )  
    Return  $t$   
}
```

An Example

```
cgen(5 + x) = {  
  Choose a new temporary  $t$   
  Let  $t_1 = \mathbf{cgen}(5)$   
  Let  $t_2 = \mathbf{cgen}(x)$   
  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 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  $t = \mathbf{cgen}(expr)$   
  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  $t = \mathbf{cgen}(expr)$   
  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  $t = \mathbf{cgen}(expr)$   
  Emit( ifz  $t$  Goto  $L_{after}$  )  
  cgen(stmt)  
  Emit( Goto  $L_{before}$  )  
  Emit(  $L_{after}$  : )  
}
```

Pregled

- 1 Troadresni kod
- 2 Troadresni kod za objekte
- 3 Generisanje troadresnog koda
- 4 Literatura**

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/>