Imperative and Object-Oriented Languages

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Course IN4303, 2012/13
Compiler Construction

Assessment

last lecture

Assessment

last lecture

Explain the properties of language using the examples of English and MiniJava.

Assessment

last lecture

Explain the properties of language using the examples of English and MiniJava.

- arbitrary
- symbolic
- systematic
- productive
- non-instinctive
- conventional
- modifiable

Assessment

last lecture

Assessment

last lecture

What is a software language?

Assessment

last lecture

What is a software language?

- computer-processable artificial language used to engineer software
- piece of software

Assessment
last lecture

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Why is MiniJava a software language?

Assessment

last lecture

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- computer-processable artificial language used to engineer software
- piece of software

Why is MiniJava a software language?

- computer-processable artificial language
- programming language, can be used to engineer software
- MiniJava compiler = piece of software

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- MiniJava compiler = piece of software

Why is English not a software language?

Assessment

last lecture

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- computer-processable artificial language used to engineer software
- piece of software

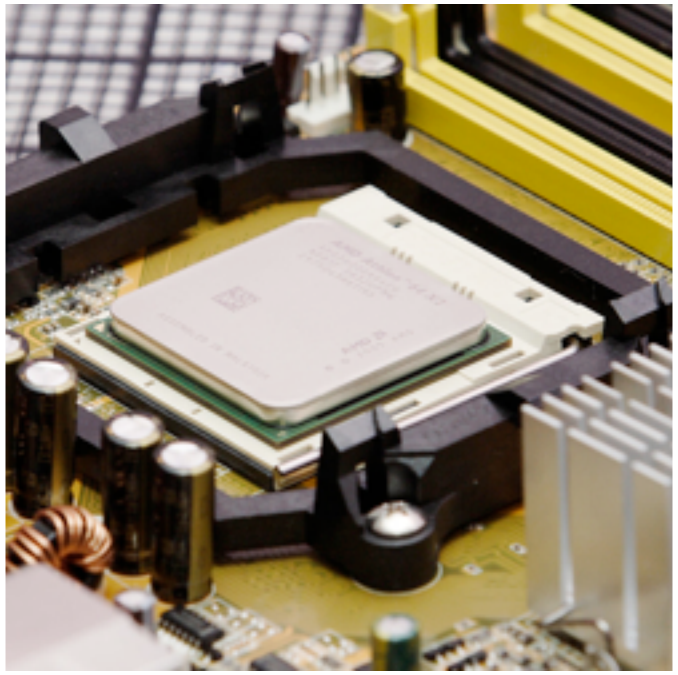
Why is MiniJava a software language?

- computer-processable artificial language
- programming language, can be used to engineer software
- MiniJava compiler = piece of software

Why is English not a software language?

- not computer-processable, not artificial

Recap: Compilers



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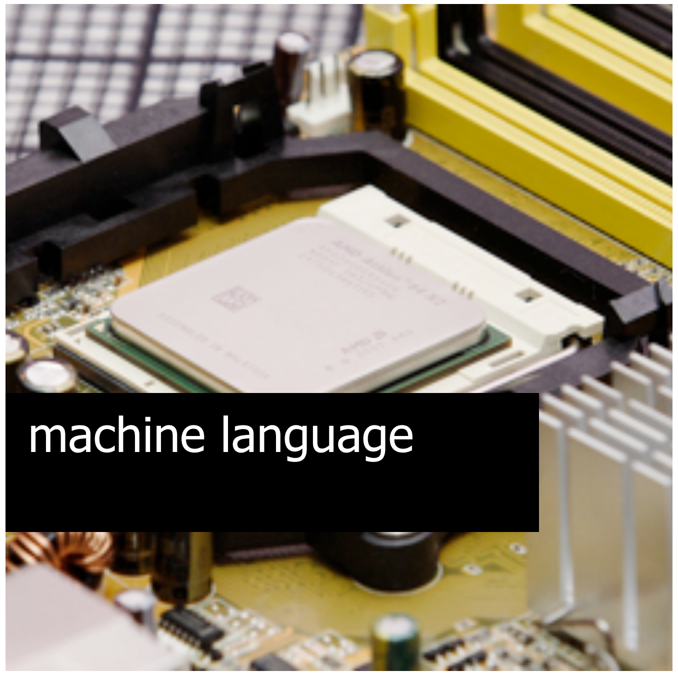

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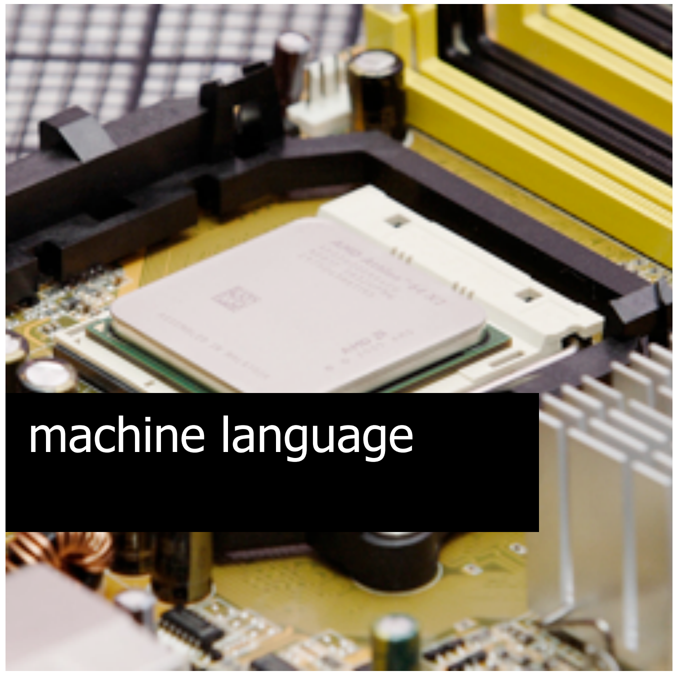

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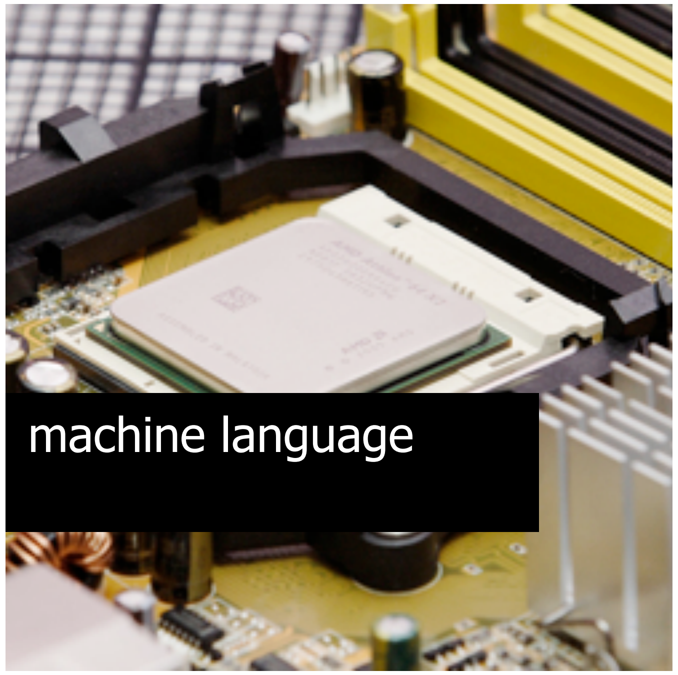
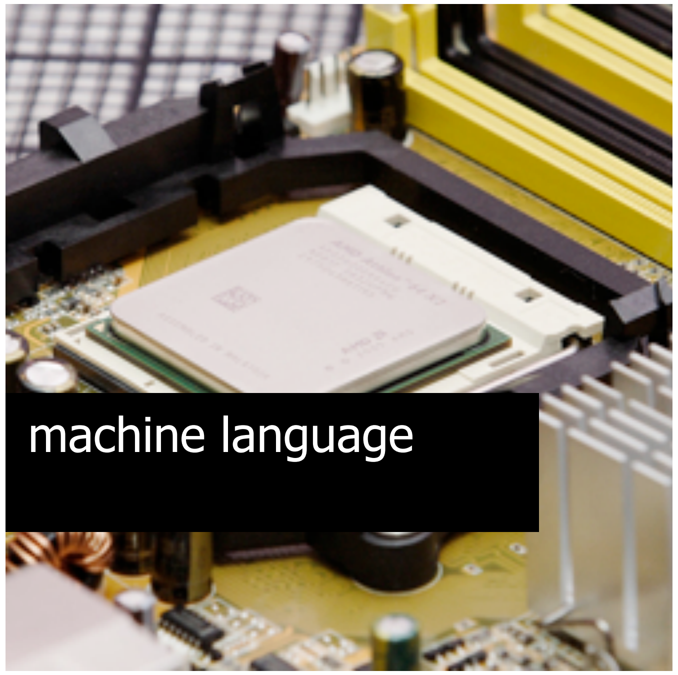


Recap: Compilers

artificial language

Compiler

machine language



Overview

today's lecture

imperative languages

- state & statements
- abstraction over machine code
- control flow and procedures
- types

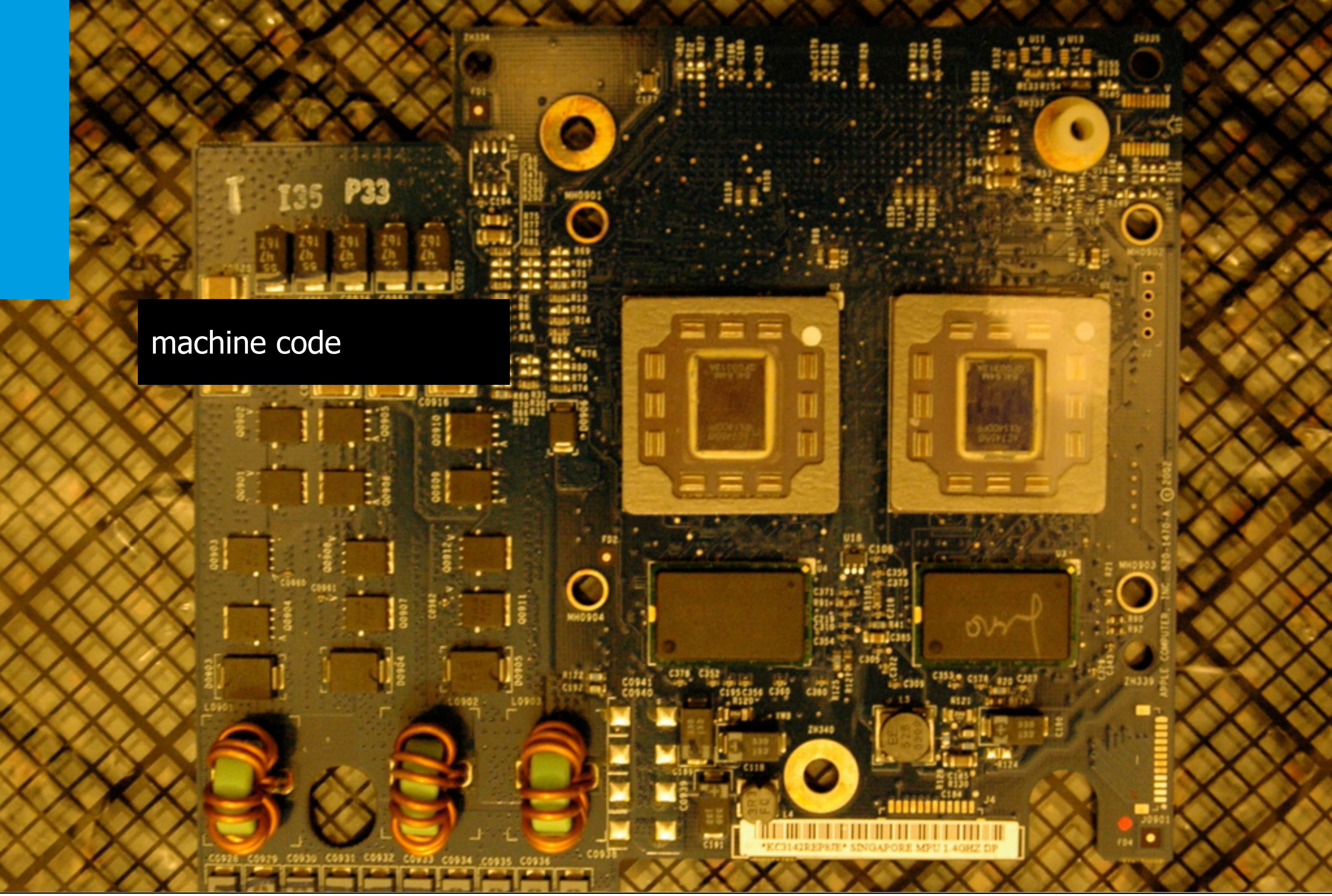
object-oriented languages

- objects & messages
- classes
- inheritance
- types

I

imperative languages

machine code



x86 family

registers

general purpose registers

- accumulator AX - arithmetic operations
- counter CX - shift/rotate instructions, loops
- data DX - arithmetic operations, I/O
- base BX - pointer to data
- stack pointer SP, base pointer BP - top and base of stack
- source SI, destination DI - stream operations

x86 family

registers

general purpose registers

- accumulator AX - arithmetic operations
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- data DX - arithmetic operations, I/O
- base BX - pointer to data
- stack pointer SP, base pointer BP - top and base of stack
- source SI, destination DI - stream operations

special purpose registers

- segments SS, CS, DS, ES, FS, GS
- flags EFLAGS

Example: x86 Assembler

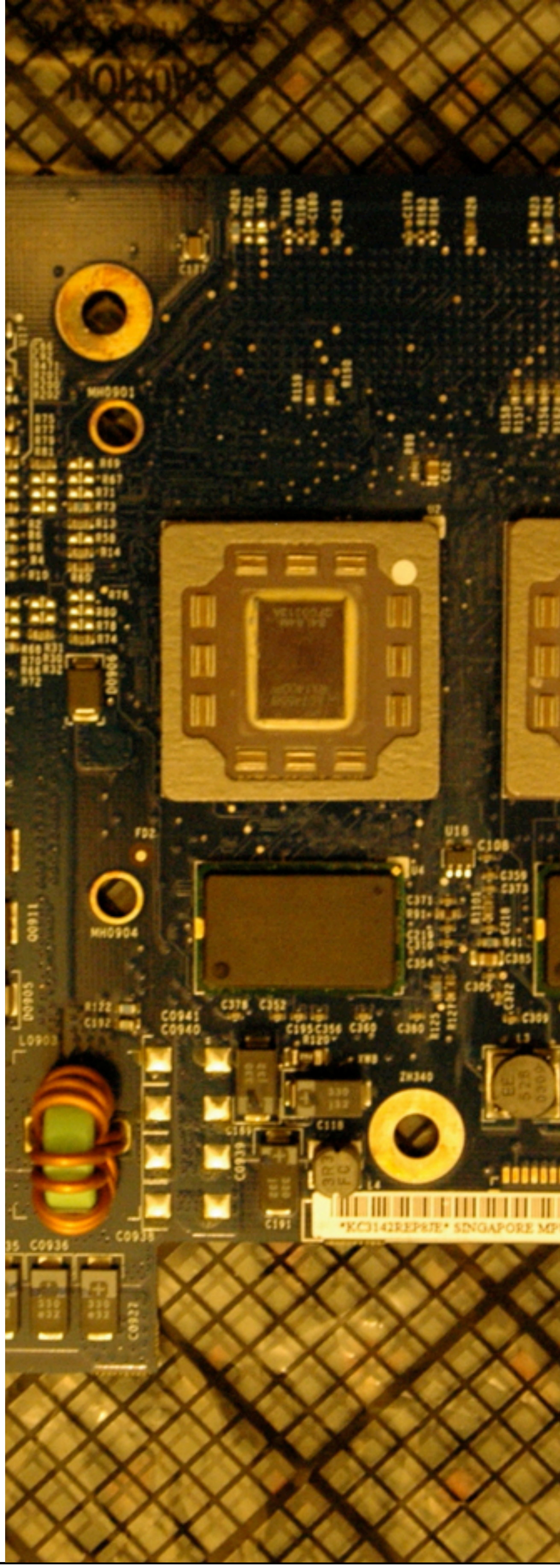
basic concepts

```
   mov AX [1]

   mov CX AX

L: dec CX
   mul CX
   cmp CX 1
   ja  L

   mov [2] AX
```



Example: x86 Assembler

basic concepts

```
    mov AX [1]        read memory

    mov CX AX

L:  dec CX
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```

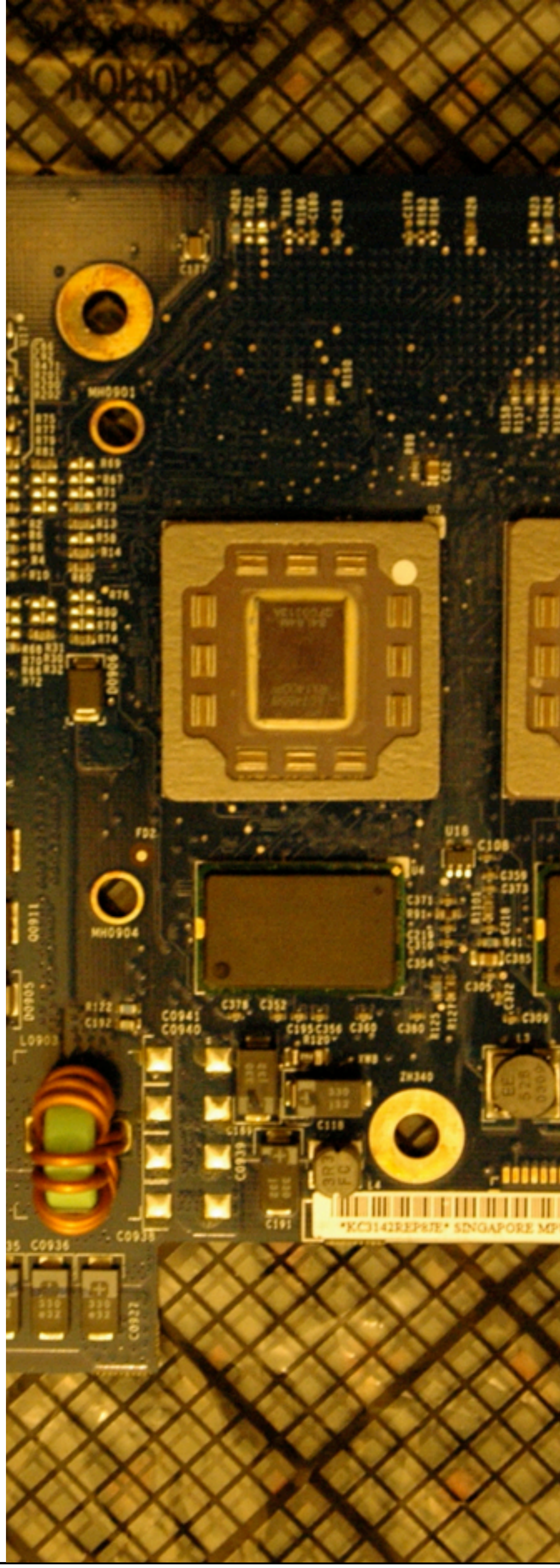

Example: x86 Assembler

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mov AX [1]          read memory

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L: dec CX
   mul CX
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mov [2] AX          write memory
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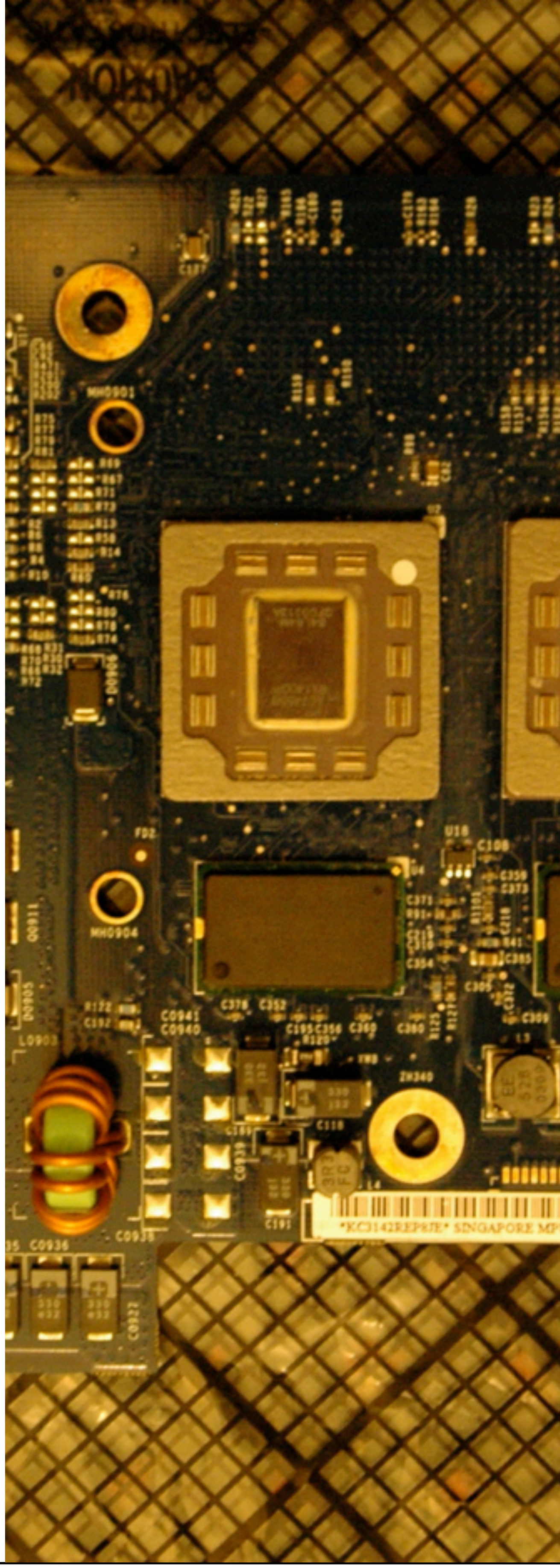
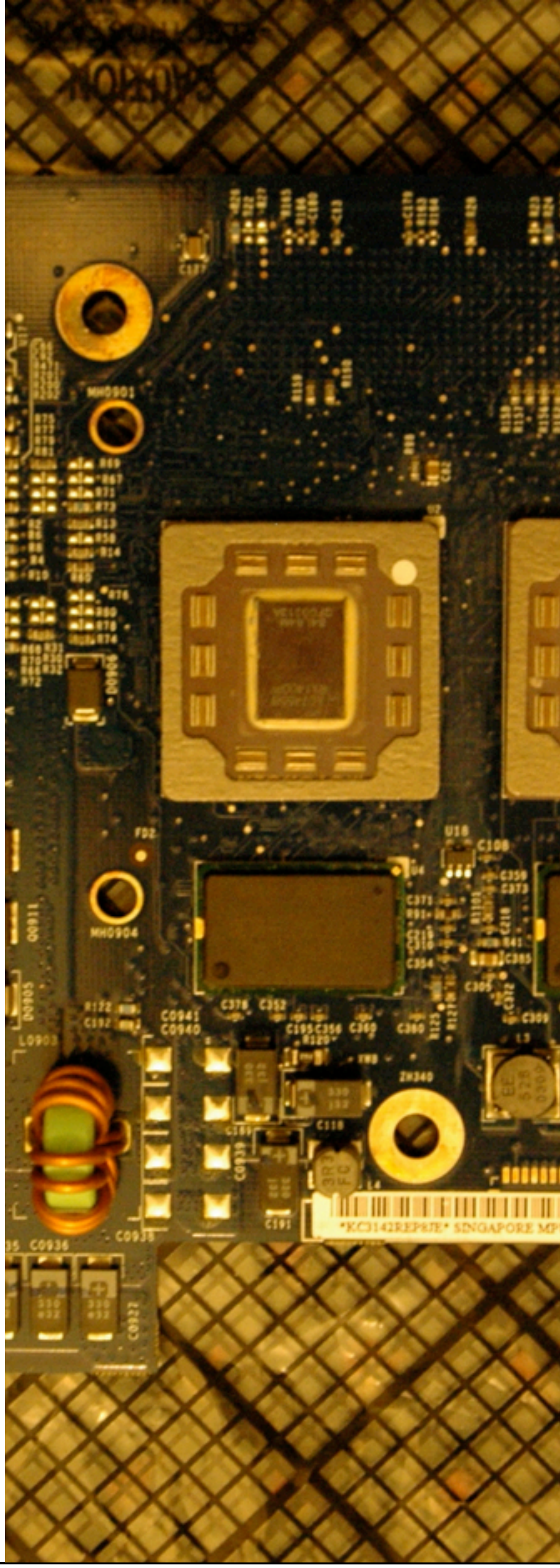


Example: x86 Assembler

basic concepts

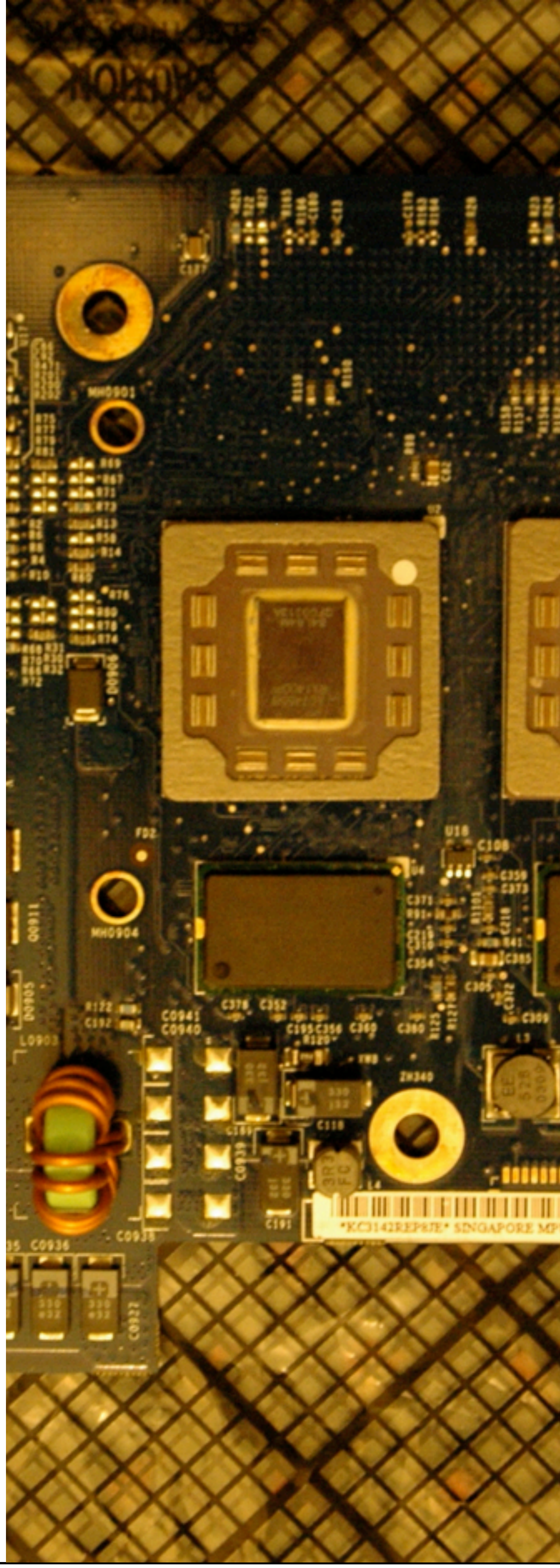
```
    mov AX [1]                read memory

    mov CX AX

L:  dec CX
    mul CX                    calculation
    cmp CX 1
    ja  L

    mov [2] AX                write memory
```



Example: x86 Assembler

basic concepts

`mov AX [1]`	read memory
`mov CX AX`	
`L: dec CX`	
`mul CX`	calculation
`cmp CX 1`	
`ja L`	jump
`mov [2] AX`	write memory



Example: Java Bytecode

basic concepts

```
.method static public m(I)I

        iload 1
        ifne else
        iconst_1
        ireturn

  else: iload 1
        dup
        iconst_1
        isub
        invokestatic Math/m(I)I
        imul
        ireturn
```

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read memory

calculation

Example: Java Bytecode

basic concepts

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        iload 1
        ifne else          jump
        iconst_1
        ireturn

else:   iload 1            read memory
        dup
        iconst_1
        isub               calculation
        invokestatic Math/m(I)I
        imul
        ireturn
```

Example: Tiger

states & statements

```
/* factorial function */

let
  var f := 1
  var x := 5
  var s := f + x
in
  while x > 1 do (
    f := x * f ;
    x := x - 1
  )
end
```

Example: Tiger

states & statements

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   while x > 1 do (
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variable

Example: Tiger

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variable

expression

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expression

assignment

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variable

expression

control flow

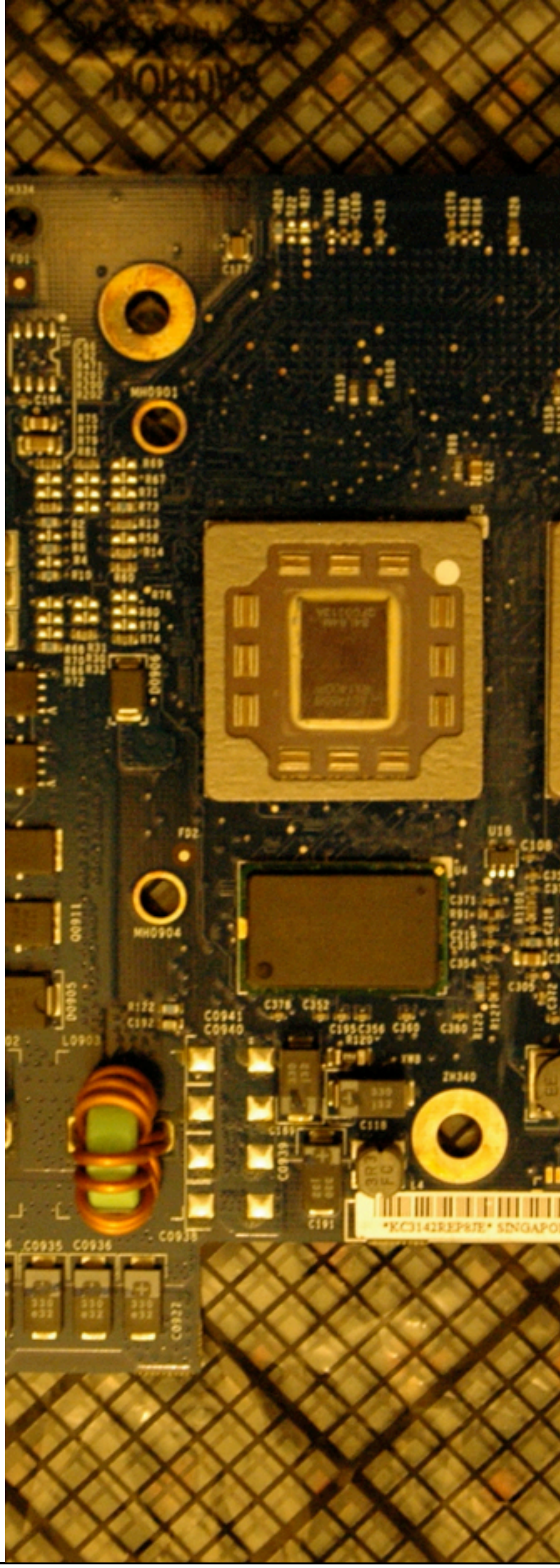
assignment

Example: x86 Assembler

modularity

```
push 21
push 42
call _f
add  SP 8
```

```
push BP
mov  BP SP
mov  AX [BP + 8]
mov  DX [BP + 12]
add  AX DX
pop  BP
ret
```



Example: x86 Assembler

modularity

```
push 21
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call _f
add  SP 8
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pass parameter

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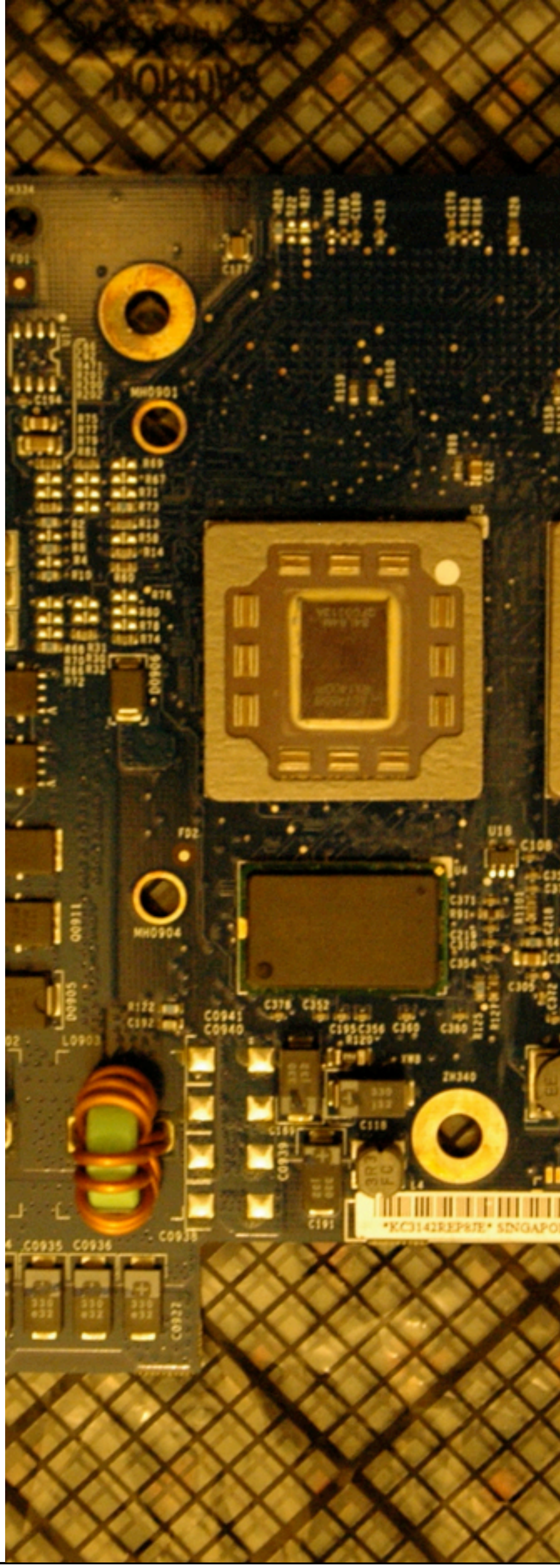

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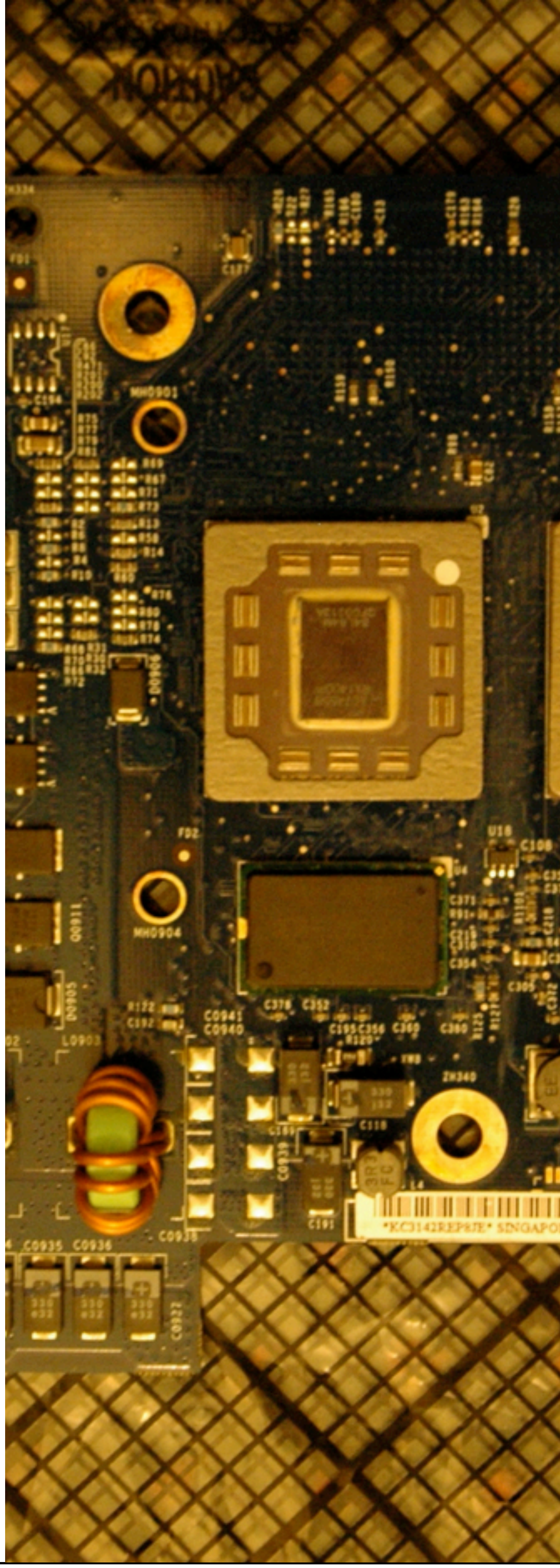
```

new stack frame



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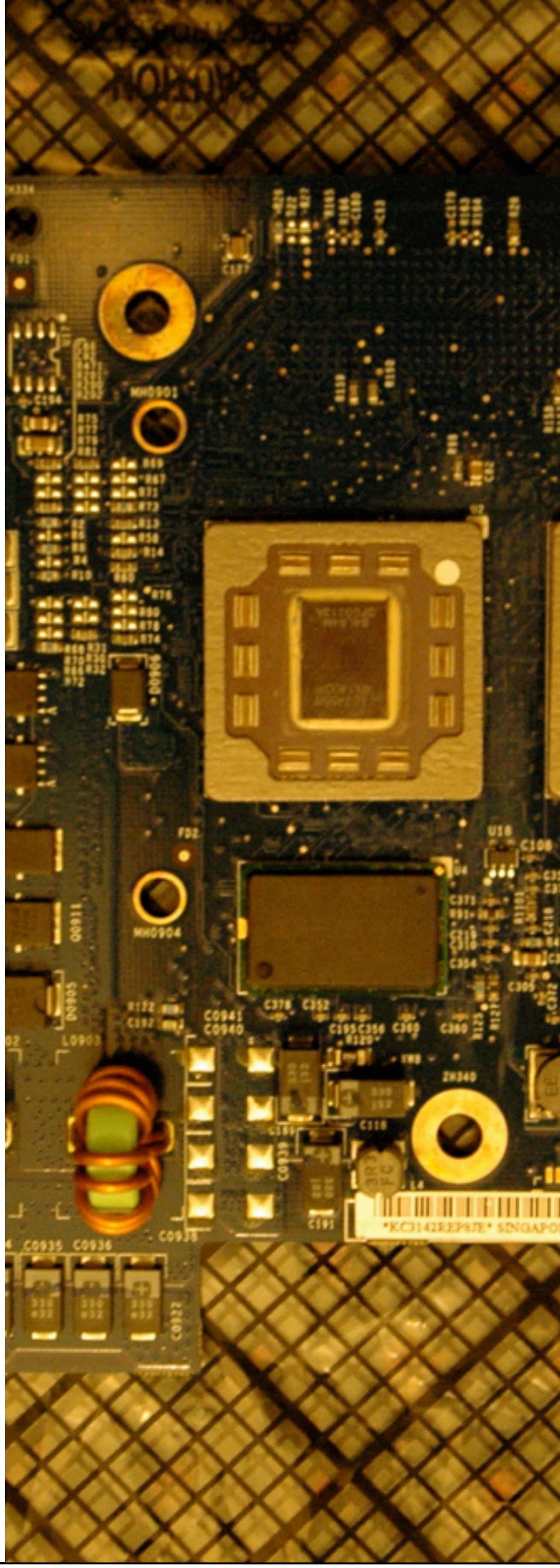
new stack frame

access parameter



Example: x86 Assembler

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push 21
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call _f
add  SP 8
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pass parameter

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```
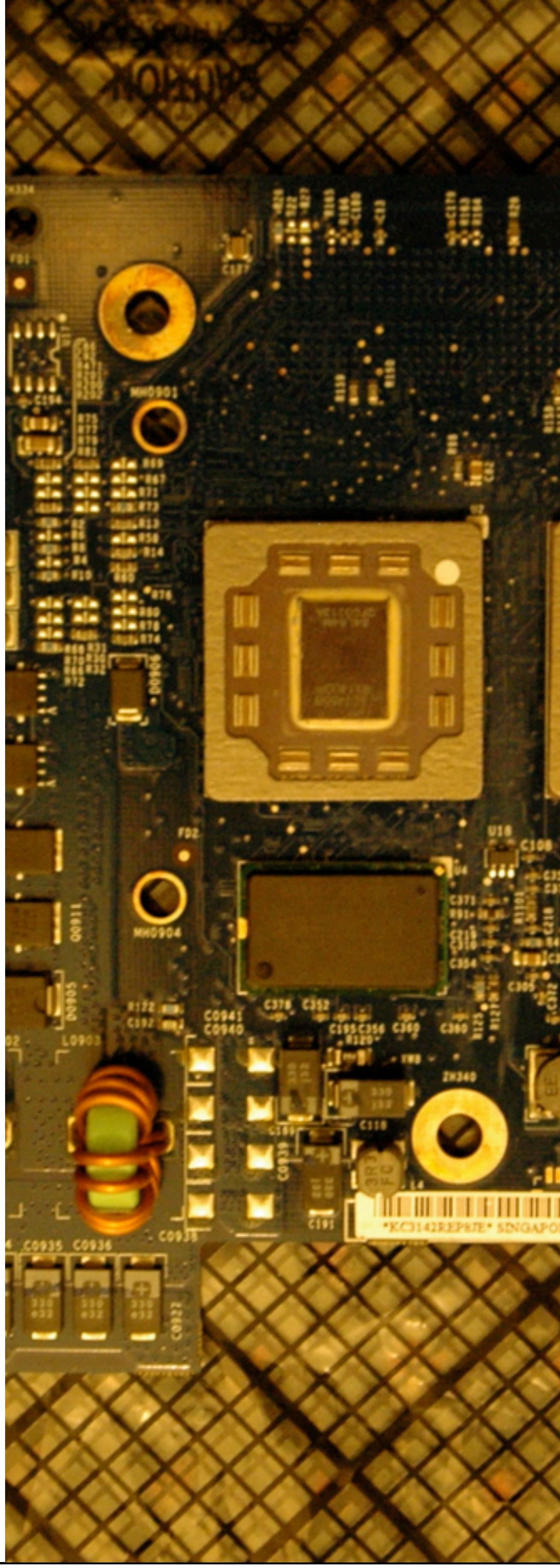

new stack frame

access parameter

old stack frame



Example: x86 Assembler

modularity

```
push 21
push 42
call _f
add  SP 8
```

pass parameter

free parameters

```
push BP
mov  BP SP
mov  AX [BP + 8]
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add  AX DX
pop  BP
ret
```
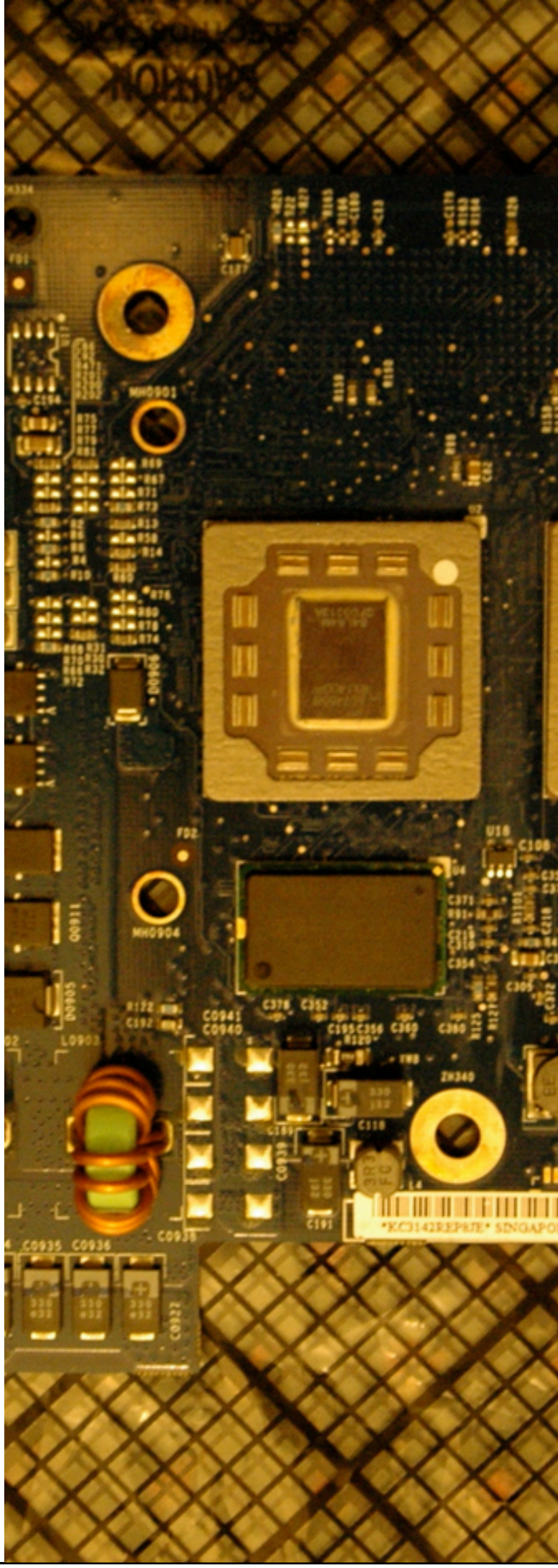

new stack frame

access parameter

old stack frame



Example: Tiger
procedures

```
/* factorial function */

let
   function fac( n: int ) : int =
      let
         var f := 1
      in
         if n < 1 then
            f := 1
         else
            f := (n * fac(n - 1) );
         f
      end
   var f := 0
   var x := 5
in
   f := fac( x )
end
```

Example: Tiger

procedures

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/* factorial function */

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   function fac( n: int ) : int =
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         var f := 1
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         f
      end
   var f := 0
   var x := 5
in
   f := fac( x )
end
```

formal parameter

Example: Tiger

procedures

```
/* factorial function */

let
    function fac( n: int ) : int =        formal parameter
        let
            var f := 1
        in
            if n < 1 then
                f := 1
            else
                f := (n * fac(n - 1) );
            f
        end
    var f := 0
    var x := 5
in
    f := fac( x )                           actual parameter
end
```

Example: Tiger

procedures

```
/* factorial function */

let
   function fac( n: int ) : int =
      let
        var f := 1
      in
         if n < 1 then
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         else
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         f
      end
   var f := 0
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in
   f := fac( x )
end
```

formal parameter

local variable

actual parameter

Example: Tiger

procedures

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/* factorial function */

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   function fac( n: int ) : int =
      let
         var f := 1
      in
         if n < 1 then
            f := 1
         else
            f := (n * fac(n - 1) );
         f
      end
   var f := 0
   var x := 5
in
   f := fac( x )
end
```

formal parameter

local variable

recursive call

actual parameter

Example: Tiger

call by value vs. call by reference

```
let
   type vector = array of int

   function init(v: vector) =
      v := vector[5] of 0

   function upto(v: vector, l: int) =
      for i := 0 to l do
         v[i] := i

   var v : vector := vector[5] of 1
in
   init(v) ;
   upto(v, 5)
end
```

Type Systems

dynamic & static typing

machine code

- memory: no type information
- instructions: assume values of certain types

Type Systems
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- memory: no type information
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dynamically typed languages

- typed values
- run-time checking & run-time errors

Type Systems

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dynamically typed languages

- typed values
- run-time checking & run-time errors

statically typed languages

- typed expressions
- compile-time checking & compile-time errors

Type Systems
compatibility

type compatibility

- value/expression: actual type
- context: expected type

Type Systems
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type equivalence

- structural type systems
- nominative type systems

Type Systems
compatibility

type compatibility

- value/expression: actual type
- context: expected type

type equivalence

- structural type systems
- nominative type systems

subtyping

- relation between types
- value/expression: multiple types

Example: Tiger

type compatibility

```
    let
    type A = int
    type B = int
    type V = array of A
    type W = V
    type X = array of A
    type Y = array of B

    var a: A := 42
    var b: B := a
    var v: V := V[42] of b
    var w: W := v
    var x: X := w
    var y: Y := x
in
    y
end
```

Type Systems
record types

record

- consecutively stored values
- fields accessible via different offsets

record type

- fields by name, type, position in record
- structural subtyping: width vs. depth

```
type R1 = {f1 : int, f2 : int}
type R2 = {f1 : int, f2 : int, f3 : int}
type R3 = {f1 : byte, f2 : byte}
```

Type Systems

polymorphism

ad-hoc polymorphism

overloading

- same name, different types, same operation
- same name, different types, different operations

type coercion

- implicit conversion

universal polymorphism

subtype polymorphism

- substitution principle

parametric polymorphism

```
21 + 21
21.0 + 21.0

print(42)
print(42.0)

"foo" + "bar"

21 + 21.0
```

coffee break

II

object-oriented languages

Modularity

objects & messages

objects

- generalisation of records
- identity
- state
- behaviour

Modularity

objects & messages

objects

- generalisation of records
- identity
- state
- behaviour

messages

- objects send and receive messages
- trigger behaviour
- imperative realisation: method calls

Modularity
classes

classes

- generalisation of record types
- characteristics of objects: attributes, fields, properties
- behaviour of objects: methods, operations, features

```
public class C {
   public int f1;
   private int f2;
   public void m1() { return; }
   private C m2(C c) { return c; }
}
```

Modularity
classes

classes

- generalisation of record types
- characteristics of objects: attributes, fields, properties
- behaviour of objects: methods, operations, features

encapsulation

- interface exposure
- hide attributes & methods
- hide implementation

```
public class C {
   public int f1;
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   public void m1() { return; }
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}
```

Modularity

inheritance vs. interfaces

inheritance

- inherit attributes & methods
- additional attributes & methods
- override behaviour
- nominative subtyping

```
public class C {
   public int f1;
   public void m1() {…}
   public void m2() {…}
}

public class D extends C {
   public int f2;
   public void m2() {…}
   public void m3() {…}
}

public interface I {
   public int f;
   public void m();
}

public class E implements I {
   public int f;
   public void m() {…}
   public void m’() {…}
}
```

Modularity

inheritance vs. interfaces

inheritance

- inherit attributes & methods
- additional attributes & methods
- override behaviour
- nominative subtyping

interfaces

- avoid multiple inheritance
- interface: contract for attributes & methods
- class: provide attributes & methods
- nominative subtyping

```
public class C {
   public int f1;
   public void m1() {…}
   public void m2() {…}
}

public class D extends C {
   public int f2;
   public void m2() {…}
   public void m3() {…}
}

public interface I {
   public int f;
   public void m();
}

public class E implements I {
   public int f;
   public void m() {…}
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}
```

Type Systems

polymorphism

Type Systems
polymorphism

ad-hoc polymorphism

overloading

- same method name, independent classes
- same method name, same class, different parameter types

overriding

- same method name, subclass, compatible types

Type Systems
polymorphism

ad-hoc polymorphism

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- same method name, independent classes
- same method name, same class, different parameter types

overriding

- same method name, subclass, compatible types

universal polymorphism

subtype polymorphism

- inheritance, interfaces

parametric polymorphism

Type Systems

static vs. dynamic dispatch

dispatch

- link method call to method

Type Systems

static vs. dynamic dispatch

dispatch

- link method call to method

static dispatch

- type information at compile-time

Type Systems

static vs. dynamic dispatch

dispatch

- link method call to method

static dispatch

- type information at compile-time

dynamic dispatch

- type information at run-time
- single dispatch: one parameter
- multiple dispatch: more parameters

Example: Java

single dispatch

```java
public class A {} public class B extends A {} public class C extends B {}

public class D {
   public A m(A a) { System.out.println("D.m(A a)"); return a; }
   public A m(B b) { System.out.println("D.m(B b)"); return b; }
}

public class E extends D {
   public A m(A a) { System.out.println("E.m(A a)"); return a; }
   public B m(B b) { System.out.println("E.m(B b)"); return b; }
}
```

```java
A a = new A(); B b  = new B(); C c  = new C(); D d = new D(); E e  = new E();
               A b1 = b;       A c1 = c;                      D e1 = e;

d. m(a); d. m(b); d. m(b1); d. m(c); d. m(c1);
e. m(a); e. m(b); e. m(b1); e. m(c); e. m(c1);
e1.m(a); e1.m(b); e1.m(b1); e1.m(c); e1.m(c1);
```

Type Systems

overriding

methods

- parameter types
- return type

Type Systems
overriding

methods

- parameter types
- return type

covariance

- method in subclass
- return type: subtype of original return type

Type Systems

overriding

methods

- parameter types
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covariance

- method in subclass
- return type: subtype of original return type

contravariance

- method in subclass
- parameter types: supertypes of original parameter types

Example: Java

overloading vs. overriding

```
public class F {
   public A m(B b) { System.out.println("F.m(B b)"); return b; }
}

public class G extends F {
   public A m(A a) { System.out.println("G.m(A a)"); return a; }
}

public class H extends F {
   public B m(B b) { System.out.println("H.m(B b)"); return b; }
}
```

```
A a = new A(); B b  = new B(); F f = new F(); G g = new G(); F h = new H();
               A b1 = b;

f.m(b);
g.m(a); g.m(b); g.m(b1);
h.m(b);
```

Example: Java

invariance

```
public class X {
   public A a;
   public A    getA()    { return a ; }
   public void setA(A a) { this.a = a ; }
}

public class Y extends X {
   public B a;
   public B    getA()    { return a ; }
   public void setA(B a) { this.a = a ; }
}
```

```
A a = new A(); B b  = new B(); X y = new Y();

y.getA(); y.setA(b); y.setA(a);

String[] s = new String[3] ; Object[] o = s ; o[1] = new A();
```

III

summary

Summary

lessons learned

Summary
lessons learned

imperative languages

- state & statements
- abstraction over machine code
- control flow & procedures
- types

Summary
lessons learned

imperative languages

- state & statements
- abstraction over machine code
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object-oriented languages

- objects & messages
- classes
- inheritance
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Literature

learn more

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learn more

Imperative Languages

Carl A. Gunter: Semantics of Programming Languages: Structures and Techniques. MIT Press, 1992

Kenneth C. Louden: Programming Languages: Principles and Practice. Course Technology, 2002

Literature
learn more

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Object-Oriented Languages

Martin Abadi, Luca Cardelli: A Theory of Objects. Springer, 1996.

Kim B. Bruce: Foundations of Object-Oriented Programming Languages: Types and Semantics. MIT Press, 2002.

Timothy Budd: An Introduction to Object-Oriented Programming. Addison-Wesley, 2002.

Outlook
coming next

declarative language definition

- Lecture 1: Grammars and Trees
- Lecture 2: SDF and ATerms
- Lecture 3: Pretty Printing
- Lecture 4: Term Rewriting
- Lecture 5: Static Analysis and Error Checking
- Lecture 6: Code Generation

Lab Sep 13

- get used to Eclipse, Spoofax, and MiniJava

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