2IMP25 Software Evolution

Code duplication

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Where innovation starts

Assignments

Assignment 1

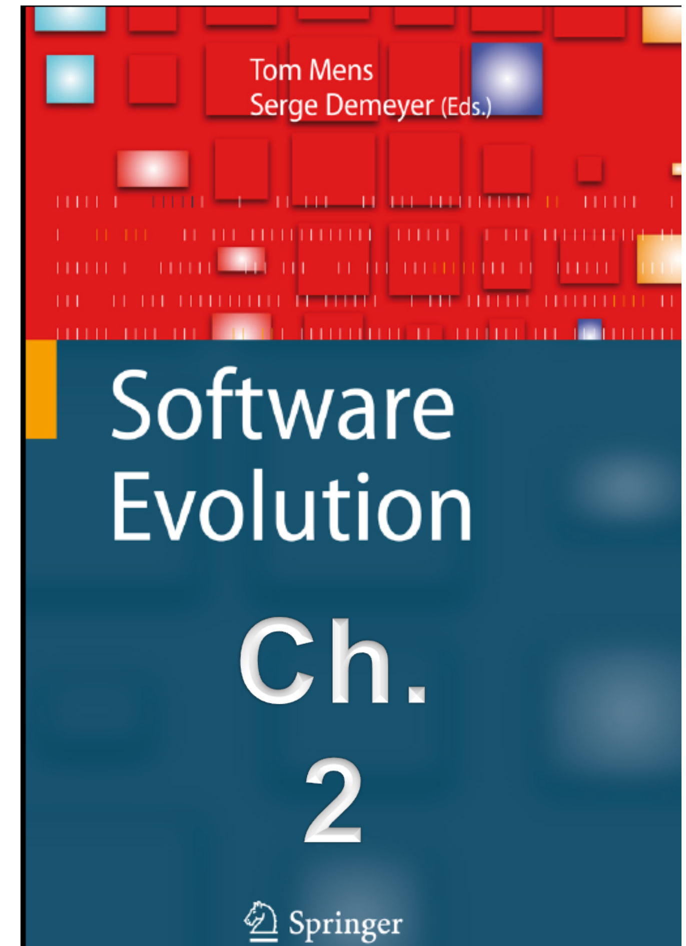
- **Median 7, mean 6.87**
- **My grades: 3-3-1-1-2-1-4**
  - You've done much better than me ;-)
  - Clear, fair grading BUT tedious
  - Good suggestion: give a specific evolution scenario
  - Less requirements: will not be realistic

Assignment 2: March 9, 2015, 23:59.

- **Architecture reconstruction**
- **Rascal**

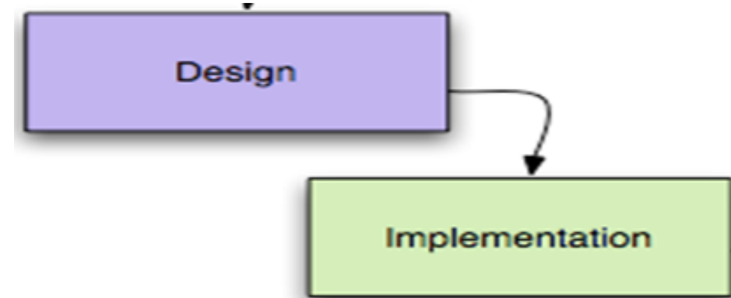
Sources

"Clone detection" slides
Rainer Koschke (in German)
http://www.informatik.uni-bremen.de/st/lehre/re09/softwareklone.pdf



Where are we now?

- Last time: architecture (+ guest lecture)
  - Behaviour
    - static/dynamic,
    - sequence diagrams/state machines,
    - focusing/visualization



- This week: code duplication
  - Occurs in the code
  - Can reflect suboptimal architecture

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Duplication?

- Beck and Fowler, "Stink Parade of Bad Smells": 1
- Common?

Author	System	Min. length (lines)	%
Baker (1995)	X Windows	30	19
Baker *et alii* (1998)	Process control	?	29
Ducasse *et alii* (1999)	Payroll	10	59

- Frequent and problematic!

A rose by any other name

- Popular terms
  - Software redundancy
    - Not every type of redundancy is harmful
  - Code cloning = Code duplication
    - Clone is identical to the original form

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A rose by any other name

- Popular terms
  - Software redundancy
    - Not every type of redundancy is harmful
  - Code cloning = Code duplication
    - Clone is identical to the original form

- Questions
  1. When are two fragments to be considered as clones?
  2. When is cloning harmful/useful?
  3. How do the clones evolve?
  4. What can one do about clones: ignore, prevent, eliminate?
  5. How to detect and present the clones?

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Clones?

```
1586 {
1587      if( GlobalConfig.DEBUG_LEVEL & DEBUG_WARNINGS ) {
1588                printf( __STR_WARNING__MEM_ALLOC_FAILED,
1589                acModuleName, pMsg->ServerName );
1590      }
1591      if( rcv_id != 0 )     {
1592      pMsg->type = TYPE_MSGUNKNOWN;
1593      MsgReply ( rcv_id, 0, pMsg, MSG_LENGTH_ACK );
1594      }
1595      return( MIRPA_ERROR_MEM_ALLOC_FAILED );
1596 }
```

```
1173 {
1174      if( GlobalConfig.DEBUG_LEVEL & DEBUG_WARNINGS ) {
1175                printf( __STR_WARNING__MEM_ALLOC_FAILED,
1176                acModuleName, pMsg->ServerName );
1177      }
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1183 }
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1182     return( MIRPA_ERROR_MEM_ALLOC_FAILED );
1183 }
```

Type 1

Clones?

```
4278 case TYPE_SHMEM:
4279      if( GlobalConfig.DEBUG_LEVEL & DEBUG_WARNINGS ) {
4280                printf( "%s: WARNING : SHMEM msg received after
4281                sending ANSWER \"%s\"\n",
4282      acModuleName,
4283      sMsgList.asTxMsg[ uiMsgHandle ].name );
4284      }
4285 return( MIRPA_ERROR_RX_UNEXPECTED_TYPE );
```

```
4270 case TYPE_MSGOK:
4271      if( GlobalConfig.DEBUG_LEVEL & DEBUG_INFO ) {
4272                printf(“%s: INFO : MSG_OK received after
4273                          sending ANSWER \"%s\"\n",
4279      acModuleName,
4280      sMsgList.asTxMsg[ uiMsgHandle ].name );
4281      }
4282 return( MIRPA_OK );
```


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Clones?

4278 case **TYPE_SHMEM:**
4279 if(GlobalConfig.DEBUG_LEVEL & **DEBUG_WARNINGS**) {
4280 printf("%s: **WARNING : SHMEM msg** received after
4281 sending ANSWER \"%s\"\n",
4282 acModuleName,
4283 sMsgList.asTxMsg[uiMsgHandle].name);
4284 }
4285 return(**MIRPA_ERROR_RX_UNEXPECTED_TYPE**);

Type 2

4270 case **TYPE_MSGOK:**
4271 if(GlobalConfig.DEBUG_LEVEL & **DEBUG_INFO**) {
4272 printf("%s: **INFO : MSG_OK** received after
4273 sending ANSWER \"%s\"\n",
4279 acModuleName,
4280 sMsgList.asTxMsg[uiMsgHandle].name);
4281 }
4282 return(**MIRPA_OK**);

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Clones?

```
if ( ! parse( ) ) {
        print_error(stdout , 0) ;
        return FALSE ;
}

fclose( fp ) ;

if ( debug_flag ) {
        printf(" result of parser ") ;
        if ( ! print_tree( FALSE ) ) {
                print_error(stdout , 0) ;
                return FALSE ;
        }
}
```

```
if ( ! type_check( ) ) {
        print_error(stdout , 0) ;
        return FALSE ;
}

if ( debug_flag ) {
        printf(" result of type check") ;
        if ( ! print_tree( TRUE ) ) {
                print_error(stdout , 0) ;
                return FALSE ;
        }
}
```

Clones?

```
if ( ! parse( ) ) {
        print_error(stdout , 0) ;
        return FALSE ;
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fclose( fp ) ;

if ( debug_flag ) {
        printf(" result of parser ") ;
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}

if ( debug_flag ) {
        printf(" result of type check") ;
        if ( ! print_tree( TRUE ) ) {
                print_error(stdout , 0) ;
                return FALSE ;
        }
}
```

Type 3

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Clones?

```
/*
By Bob Jenkins, 1996. hashtab.h Public Domain
…
htab *hcreate(/*_ word logsize _*/);

void hdestroy(/*_ htab *t _*/); */
…
```

Type 4

```
/* Copyright (C) 2002 Christopher Clark
<firstname.lastname@cl.cam.ac.uk> */
…
 struct hashtable
*create_hashtable(unsigned int minsize,
           unsigned int (*hashfunction) (void*),
           int (*key_eq_fn) (void*,void*));
…
void
hashtable_destroy(struct hashtable *h, int free_values);
```

Types are too rough!

If we want to eliminate the duplicates we need to understand the differences between them!

Method clones [Balazinska et al. 1999]

3-9 – one token only

10-12 – aggregated changes

- **Interface: 3-6**
- **Implementation: 7-9**
- **Interface and implem.: mix**

Category number	Type of clones
1	Identical
2	Superficial changes
3	Called methods
4	Global variables
5	Return type
6	Parameters types
7	Local variables
8	Constants
9	Type usage
10	Interface changes
11	Implementation changes
12	Interface and implementation changes
13	One long difference
14	Two long differences
15	Several long differences
16	One long difference, interface and implementation
17	Two long differences, interface and implementation
18	Several long differences, interface and implementation

Type 1 (categories 1-2)

Type 2 (categories 3-12)

Type 3 (categories 13-18)

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Structural classification [Kapser *et alii* 2003]

- Alternative based on the locations of the clones.

- Intra-file or inter-file cloning
- Type of location:
  - function, declaration, macro, hybrid, other (typedef)
- Type of the code sequence
  - initialization, finalization, loop, switch

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Q1: Two fragments are clones if…

- Type 1: They are identical up to whitespace/comments
- Type 2: They are structurally identical (rename variables, types or method calls)
- Type 3: They are similar but statements/expressions could have been added, removed or modified
- Type 4: They implement the same concepts

- Alternative classifications have been proposed:
  - [Balazinska et al. 1999] based on the differences
  - [Kapser et al. 2003] based on the location

Q2: Is cloning bad? Good reasons for cloning

- Improves reliability
  - *n*-version programming, IEC 61508
- Reduces development time
  - “Copy and modify” is faster than “generalize”
- Avoids breaking the existing code
  - Re-testing effort might be prohibitive
- Clarifies structure
  - E.g., disentangles dependencies (but do not overdo!)
- By lack of choice
  - Programming language does not provide appropriate flexibility mechanisms

However (bad news)…

- More code
  - More effort required to comprehend, test and modify
  - Higher resource usage

- Interrelated code
  - Bug duplication
  - Incomplete or inconsistent updates

- Indicative of
  - Poor or decaying architecture
  - Lack of appropriate knowledge sharing between the developers

Even more: duplication and bugs

- [Monden et al. 2002]
  - 2000 modules, 1MLOC Cobol
  - Most errors in modules with ≥ 200 LOC cloned
  - Many errors in modules with ≤ 50 LOC cloned
  - Least errors in modules with 50-100 LOC clones
  - No explanation of this phenomenon

- [Chou et al. 2001]
  - Linux and Open BSD kernels
  - In presence of clones: one error ⇒ many errors

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Empirical evaluation of clones [Godfrey, Kapser, 2011]

- **Systems**: Apache 2.2.4, Gnumeric 1.6.3
- **Clone groups**: 1580 in Apache, 3437 in Gnumeric
- **Random**ly select 100 clone groups from each system
- **Manual review**:
  - *Drop:* not really a clone group
  - *Good*: no better solution is possible
  - *Harmful*: better solution is obvious, cloning due to laziness
  - *Unavoidable*:
    - either too trivial to bother
    - or no alternative is possible (often the case with APIs)

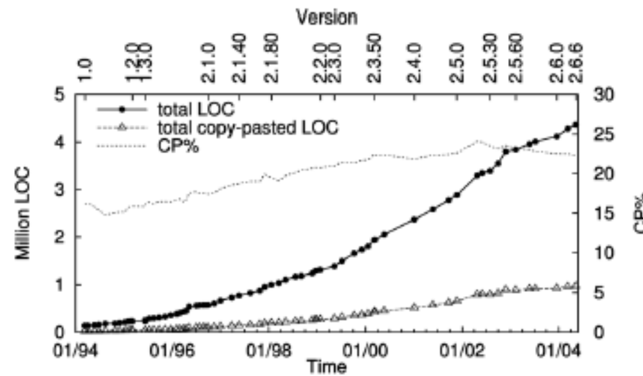
How harmful is cloning (3)

Category	Pattern	Apache: Good	Apache: Unavoidable	Apache: Harmful	Gnumeric: Good	Gnumeric: Unavoidable	Gnumeric: Harmful
Forking	Hardware variation	0	0	0	0	0	0
Forking	Platform variation	10	0	0	0	0	0
Forking	Experimental variation	4	0	0	0	0	0
Templating	Boilerplating	5	0	0	6	0	1
Templating	API protocols	0	17	0	0	8	1
Templating	Programming idioms	0	0	12	1	0	0
Templating	Parameterized code	5	1	12	10	0	24
Customizing	Bug workarounds	0	0	0	0	0	0
Customizing	Replicate and specialize	12	0	4	15	0	1
Other		3	0	8	1	0	3
Total		39	18	36	33	8	30

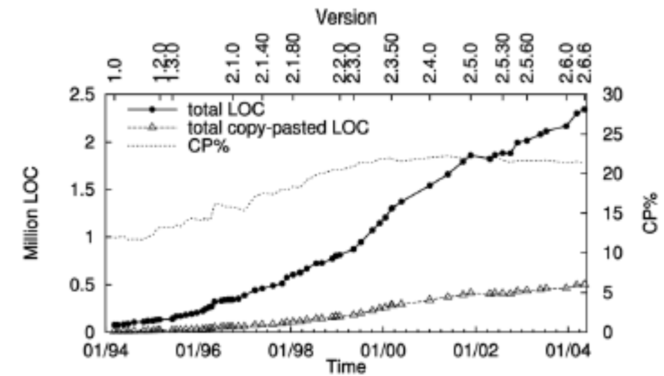
Q3. How do the clones evolve?

a) Linux
b) Linux "drivers"
c) Free BSD
d) Free BSD "sys"

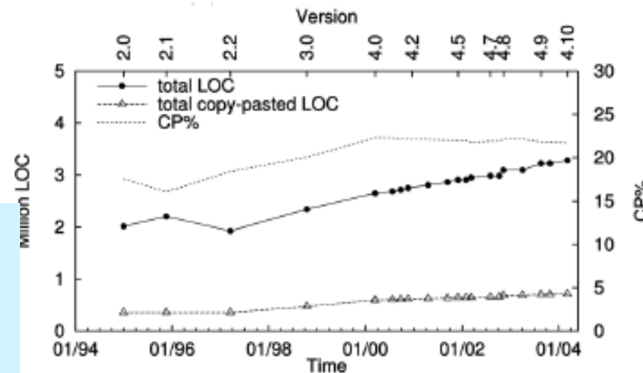
Li et al. 2006



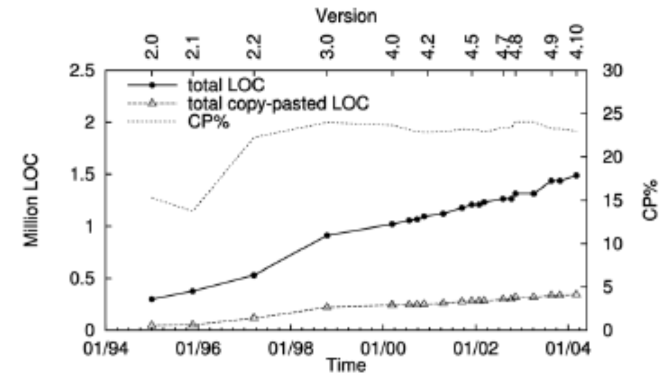
(a)



(b)



(c)



(d)

Increase followed by stabilization

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Q4. What can we do about clones?

- Ignore: the simplest way
- Correct (eliminate):
  - Manual: design patterns
  - Automated:
    - Type 1 or 2 (variable names): function abstraction
    - Type 2 (types) or 3: macros, conditional compilation
      - The programming language should support it
      - Can make the code more complex
    - Develop code generators
    - Challenges:
      - how to invent meaningful names?
      - how to determine the appropriate level of abstraction?

Q4. What can we do about clones?

- Prevent:
  - Check on-the-fly while the code is being edited
  - Check during the check-in

- Manage
  - Link the clones (automatically or manually)
  - Once one of the clones is being modified the user is notified that other clones might require modification as well.

Questions and answers so far…

1. When are two fragments to be considered as clones?
   - Type 1, 2, 3, 4
   - More refined classification possible
2. When is cloning harmful/useful?
   - reliability, reduced time, structure?, code preservation
   - more interrelated code, more bugs
3. How do the clones evolve?
   - Increase followed by stabilization
4. What can one do about clones?
   - ignore, eliminate, prevent (check on the fly), manage (link and notify the user upon change)

Q5. How to detect clones?

- Granularity
  - Classes, functions, statements
- Objects of comparison
  - Text, identifiers, tokens, AST, control and data dependencies
- Related techniques
  - textual diff, dot plot, data mining, suffix tree, tree and graph matching, latent semantic indexing, metric vector comparison, hashing

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Basic challenges in clone detection

- **Pairwise comparison of classes, functions, lines**
  - **Naïve way: $O(n^2)$**
  - **Might become prohibitive for large systems**

- **Type 2: How to abstract from var. names, types, …?**
  - **Rename all variables to XXX?**
  - **We still want to know whether the same variable appeared in different statements or not?**

- **Type 3: Clones can be combined into larger clones**
  - **Clones can have "gaps"**
  - **Identity vs. Similarity – similarity measures?**

Basic challenges in clone detection

- Pairwise comparison of classes, functions, lines
  - Naïve way: $O(n^2)$
  - Might
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  - Renar
  - We sti able appea
- Type 3: Clones can be combined into larger clones
  - Clones can have “gaps”
  - Identity vs. Similarity – similarity measures?

We are going to see how these challenges are addressed by different clone detection approaches.

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Clone detection techniques

- Text-based
  - [Ducasse et al. 1999, Marcus and Maletic 2001]
- Metrics-based
  - [Mayrand et al. 1996]
- Token-based
  - [Baker 1995, Kamiya et al. 2002]
- AST-based
  - [Baxter 1996]
  - AST+Tokens combined [Koschke et al. 2006]
- Program Dependence Graph
  - [Krinke 2001]

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Textual comparison

- **Programs are just text!**
- **“Programming language independent”**

- **[Ducasse et al, 1999]**
  - **Remove whitespaces and comments**

This is the house that Jack built.

This is the rat
That ate the malt
That lay in the house that Jack built.

This is the cat,
That killed the rat,
That ate the malt
That lay in the house that Jack built.

Textual comparison

- **Programs are just text!**
- **“Programming language independent”**

- **[Ducasse et al, 1999]**
  - **Remove whitespaces and comments**
  - **Calculate hashes for code lines**

ThisisthehousethatJackbuilt.

Thisistherat
Thatatethemalt
ThatlayinthehousethatJackbuilt.

Thisisthecat,
Thatkilledtherat,
Thatatethemalt
ThatlayinthehousethatJackbuilt.

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Textual comparison

- **Programs are just text!**
- **“Programming language independent”**
- **[Ducasse et al, 1999]**
  - **Remove whitespaces and comments**
  - **Calculate hashes for code lines**
  - **Partition lines into classes based on hashes**

ThisisthehousethatJackbuilt. **1**

Thisistherat **1**
Thatatethemalt **f**
ThatlayinthehousethatJackbuilt. **b**

Thisisthecat, **b**
Thatkilledtherat, **6**
Thatatethemalt **f**
ThatlayinthehousethatJackbuilt. **b**

Textual comparison

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- **[Ducasse et al, 1999]**
  - **Remove whitespaces and comments**
  - **Calculate hashes for code lines**
  - **Partition lines into classes based on hashes**
  - **Compare lines in the same partition**

ThisisthehousethatJackbuilt. **1**
Thisistherat

Thatkilledtherat, **6**

Thisisthecat, **b**
ThatlayinthehousethatJackbuilt.
ThatlayinthehousethatJackbuilt.

Thatatethemalt **f**
Thatatethemalt

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Textual comparison

- **Programs are just text!**
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  - **Calculate hashes for code lines**
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  - **Compare lines in the same partition**
  - **Visualize using dot plot**

ThisisthehousethatJackbuilt.

Thisistherat

Thatkilledtherat,

Thisisthecat,

ThatlayinthehousethatJackbuilt.
ThatlayinthehousethatJackbuilt.

Thatatethemalt
Thatatethemalt

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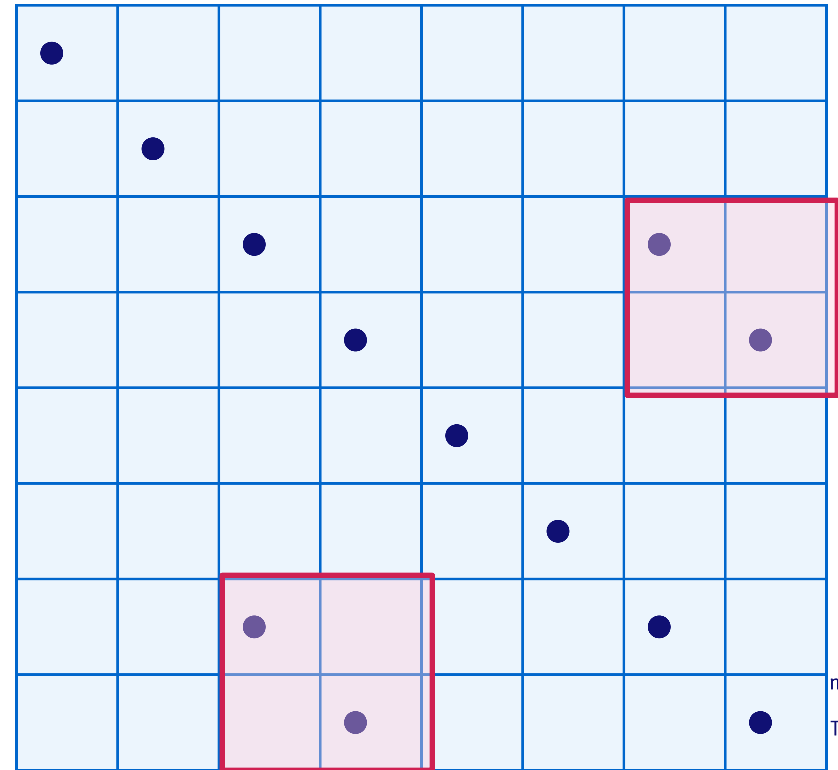
Textual comparison

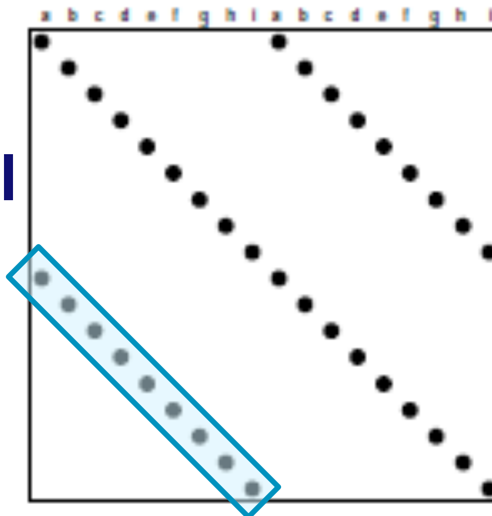
- **Programs are just text!**
- **“Programming language independent”**
- **[Ducasse et al, 1999]**
  - **Remove whitespaces and comments**
  - **Calculate hashes for code lines**
  - **Partition lines into classes based on hashes**
  - **Compare lines in the same partition**
  - **Visualize using dot plot**
  - **Recognize larger clones by dot plot patterns**



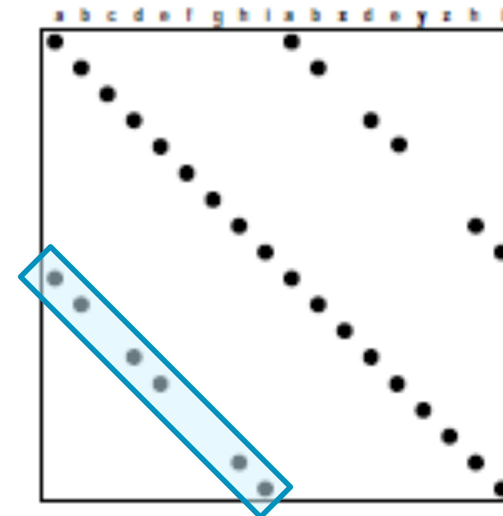
Dot plot patterns

[Ducasse et al., 1999]

Identical code clones, Type 1



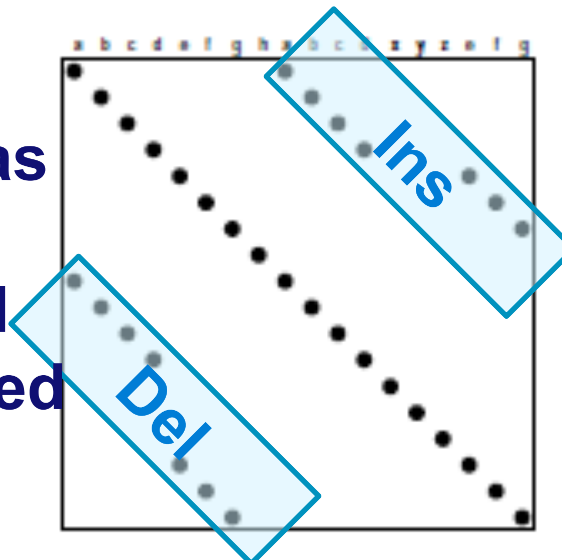
a) Diagonals



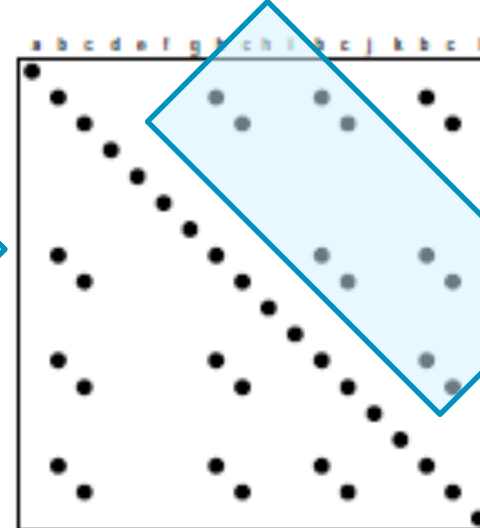
b) Diagonals with holes

Modified clones Type 2-3

Code has been inserted or deleted Type 3



c) Broken Diagonals



d) Rectangles

Recurrent code (break; preprocess)

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Advantages and disadvantages

- Good news
  - Language independent
  - Can detect Type 1,2,3 clones

- Bad news
  - Granularity: line of code, cannot detect duplication between parts of lines
  - Almost no distinction between "important" and "not important" code parts
    - Variable names
    - Syntactic sugar: if (a==0) {b}

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Alternative textual comparison approach

- [Marcus and Maletic 2001]: Clones discuss the same concepts
  - Higher-level clones: Type 4!
  - Identifier names should be the same!
    - If/while/… can be neglected
  - Latent semantic analysis (Information retrieval)
  - Mosaic 2.7, C, 269 files

Linked lists: list.c, list.h, listP.h

Two additional implementations: hotlist and HTList

Two more!

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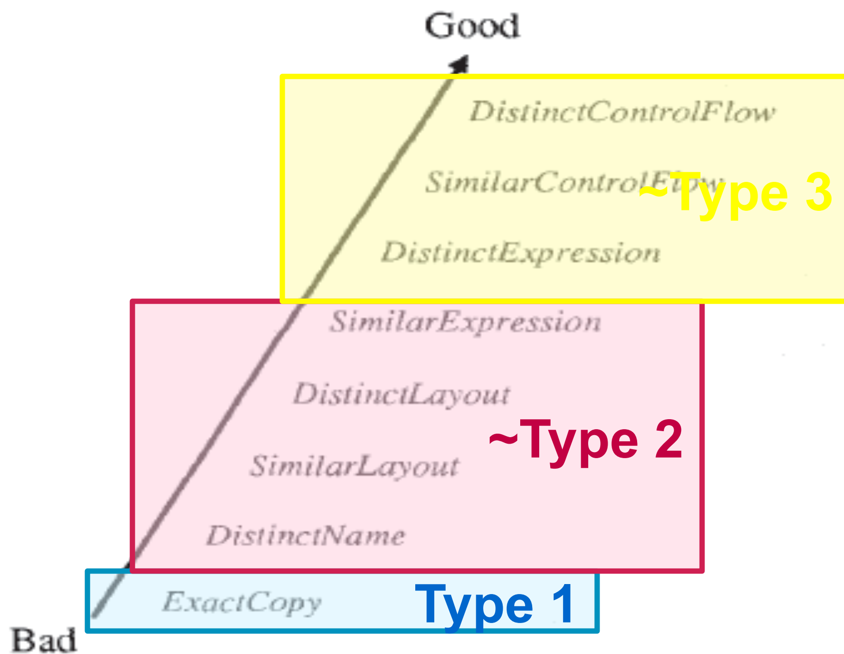
Extending the text-based approach

- Program structure instead of text
- Metrics instead of hash-functions [Mayrand et al. 1996]
  - Name: identical or not
  - Layout (5 metrics):
    - avg variable name length, num of blank lines…
  - Expression (5 metrics):
    - num of calls, num of executable statements, …
  - Control flow (11 metrics):
    - num of loops, num of decisions, …
- Many metrics $\Rightarrow$ lower chance of occasional collisions

Metrics-based clone detection



Scale	Nam	Lay	Exp	Con
1-ExactCopy	=	=	=	=
2-DistinctName	!=	=	=	=
3-SimilarLayout	X	~	=	=
4-DistinctLayout	X	!=	=	=
5-SimilarExpression	X	X	~	=
6-DistinctExpression	X	X	!=	=
7-SimilarControlFlow	X	X	X	~
8-DistinctControlFlow	X	X	X	!=

- = all metrics are equal
- ~ some metrics not equal but all differences are within the allowed range (per metrics)
- != outside the range
- X not considered

Metrics-based approaches: Discussion

- Problems:
  - Metrics are not independent (num uni calls ≤ num calls)
  - "Allowed range" is arbitrarily chosen
  - Precision?
    - $Code_1 = Code_2 \Rightarrow Metrics(Code_1) = Metrics(Code_2)$
    - $Code_1 \sim Code_2 \Rightarrow Metrics(Code_1) \sim Metrics(Code_2)$
    - $Metrics(Code_1) = Metrics(Code_2) \Rightarrow Code_1 = Code_2$?
    - $Metrics(Code_1) \sim Metrics(Code_2) \Rightarrow Code_1 \sim Code_2$???
  - Precision can be improved if metrics are combined with textual comparison
    - Still $O(n^2)$
    - But n is small for the "good choice" of metrics

More fine-grained approaches: Tokens!

- [Baker 1995]
- We want to recognize x=x+y and u=u+v as clones

- Identify tokens in the code
  - Ignore the keywords.
- Split structure and parameters

```
j = length(list);

if (j < 3) { x = x + y; }
```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- [Baker 1995]
- We want to recognize x=x+y and u=u+v as clones

- Identify tokens in the code
  - Ignore the keywords.
- Split structure and parameters
- For every structure invent an identifier

α = ( )

β if (<) { = + }

j length list

j 3 x x y

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More fine-grained approaches: Tokens!

- [Baker 1995]
- We want to recognize x=x+y and u=u+v as clones

- Identify tokens in the code
  - Ignore the keywords.
- Split structure and parameters
- For every structure invent an identifier
- Drop the structures and merge the identifiers with the parameters: P-string
- Concatenate the P-strings

α = ( )

β if (<) { = + }

j length list

j 3 x x y

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More fine-grained approaches: Tokens!

- [Baker 1995]
- We want to recognize x=x+y and u=u+v as clones

- Representation of the program so far:
- Encode the parameters:
  - First time encountered: 0
  - Next time: distance from the previous occurrence (structure identifiers included)

α j length list β j 3 x x y

α 0 0 0 β 4 0 0 1 0

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More fine-grained approaches: Tokens!

- **[Baker 1995]**

- **Clones – repeated fragments**
- **Construct a suffix tree**
  - **Represents all suffixes**
  - **Can be done in O(n)**
  - **~ Every branch represents a clone**

α y β y α x α x

α 0 β 2 α 0 α 2 $

y β y α x α x

0 β 2 α 0 α 2 $

β y α x α x

β 0 α 0 α 2 $

0 α 0 α 2 $

α 0 α 2 $

0 α 2 $

α 0 $

0 $

$

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More fine-grained approaches: Tokens!

- **[Baker 1995]**

0 α 2 $
2 $
α
$
0
β 2 α 0 α 2 $
$
β 0 α 0 α 2 $
α 0 α 2 $
α 0
$
β 2 α 0 α 2 $

Every branch up to a leaf represents a clone

Size: count the symbols on the branches

α 0 β 2 α 0 α 2 $
0 β 2 α 0 α 2 $
β 0 α 0 α 2 $
0 α 0 α 2 $
α 0 α 2 $
0 α 2 $
α 0 $
0 $
$

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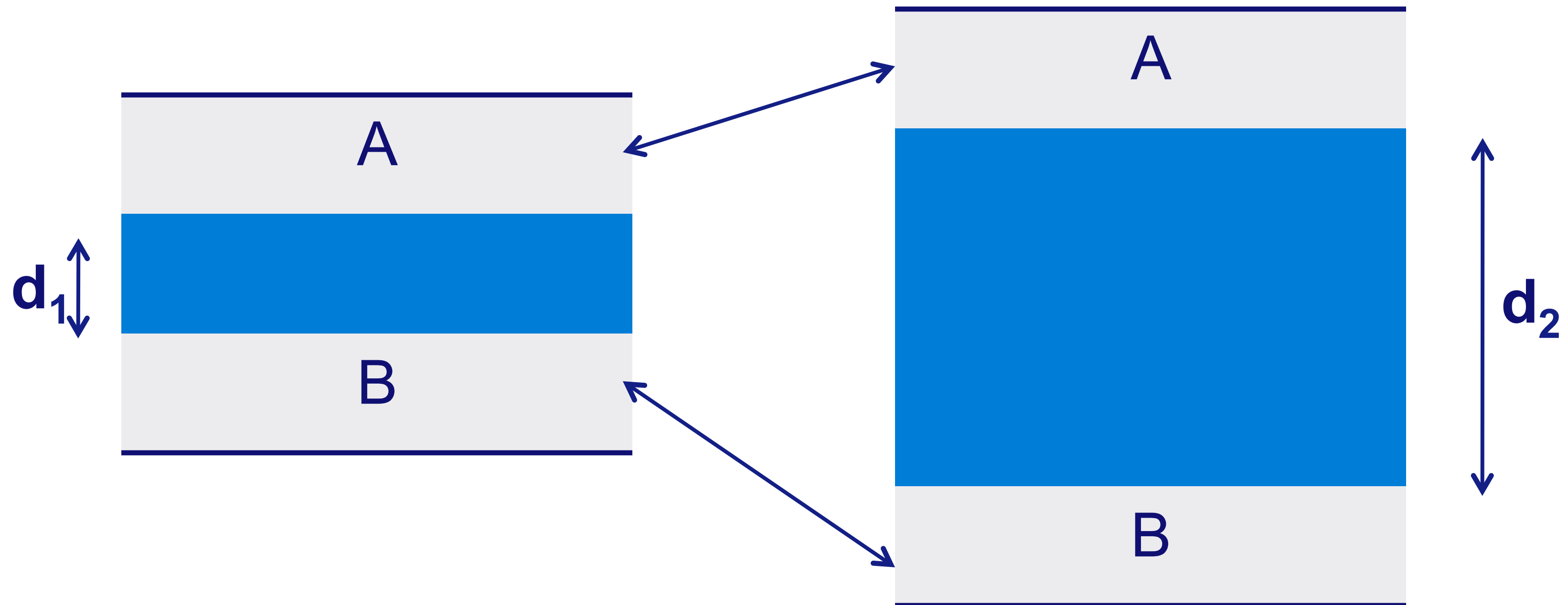
So far only Type 1 and Type 2 clones

- **Type 3 clones – combination of Type 1/2 clones**



- **Type 3 clones can be recognized if**
  - **$d_1 = d_2$**
  - **$\max(d_1, d_2) \leq$ threshold**

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Baker's approach

- Very fast:
  - 1.1 MLOC
  - minimal clone size: 30 LOC
  - 7 minutes on SGI IRIX 4.1, 40MHz, 256 MB
- Close to language independence
  - Depends solely on the tokenizer
- Can be improved by code normalization
  - See next slide
- Can identify duplication across function borders
  - Might require pre/post-processing

Code normalization (Kamiya et al. 2002)

- **Many ways to express the same intention**

x = y + x	x = x+ y	Sort the operands of commutative operations lexicographically

if (a == 1) x=1;	if (a == 1) {
	x=1;
	}
		Add { } and newlines

static global variables in C		Drop "static"

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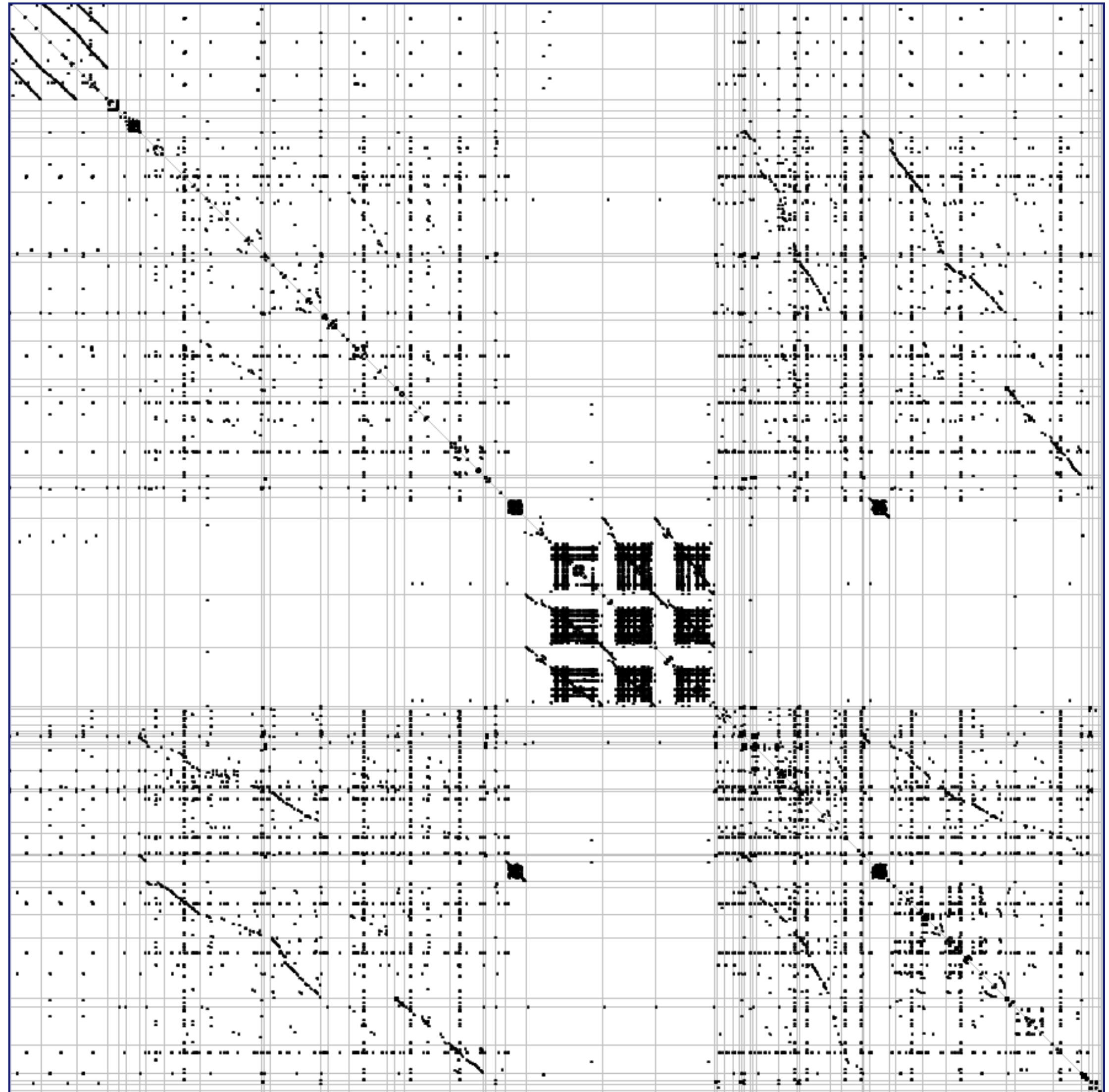
Case study: Expert system of an insurance company [Kamiya – CCFinder/Gemini]

- **Diacritics elimination**
- **Product line like variants**



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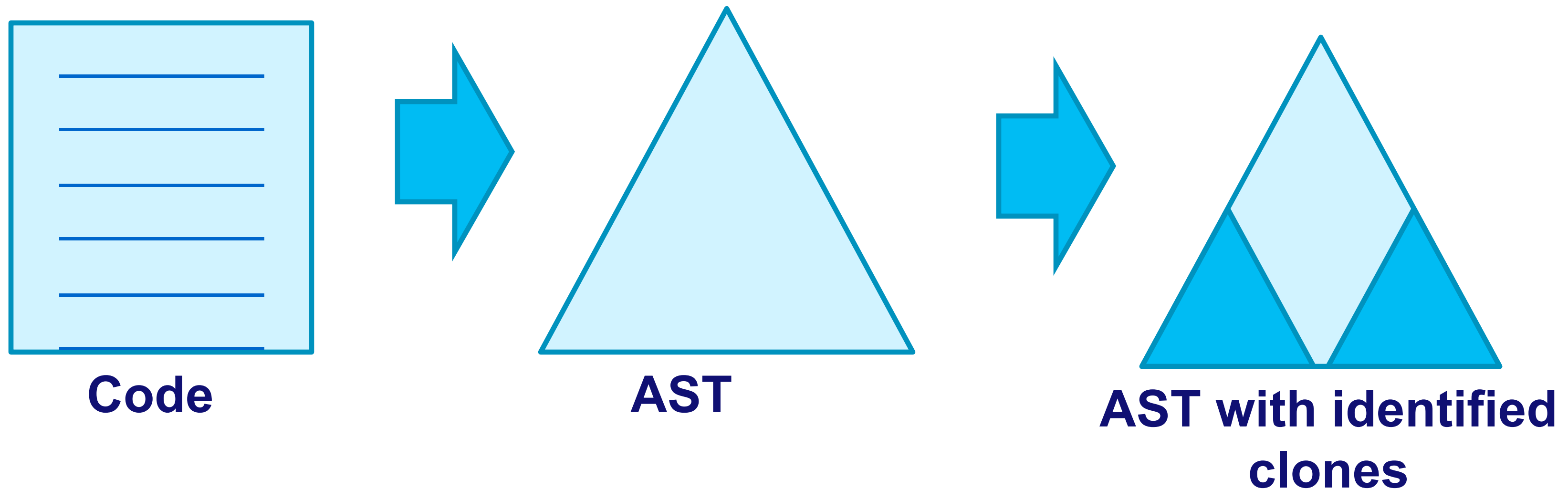
AST-based clone detection [Baxter 1996]

- If we have a tokenizer we might also have a parser!
  - Applicability: the program should be parseable



- Compare every subtree with every other subtree?
  - For an AST of n nodes: $O(n^3)$
- Similarly to text: Partitioning with a hash function
  - Works for Type 1 clones

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AST-based detection

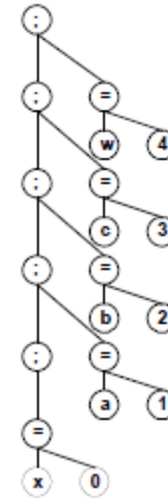
- **Type 2**
  - **Either take a bad hash function ignoring small subtrees, e.g., names**
  - **Or replace identity by similarity**

$$Similarity(T_1, T_2) = \frac{2 * Same(T_1, T_2)}{2 * Same(T_1, T_2) + Difference(T_1, T_2)}$$

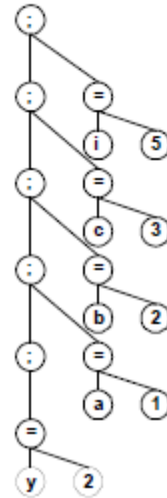
- **Type 3**
  - **Sequences of subtrees**
  - **Go from Type 2-cloned subtrees to their parents**

- **Rather precise but still slow**

```
void f ()
{
  x=0;
  a=1;
  b=2;
  c=3;
  w=4;
}
```



```
void g ()
{
  y=2;
  a=1;
  b=2;
  c=3;
  i=5;
}
```



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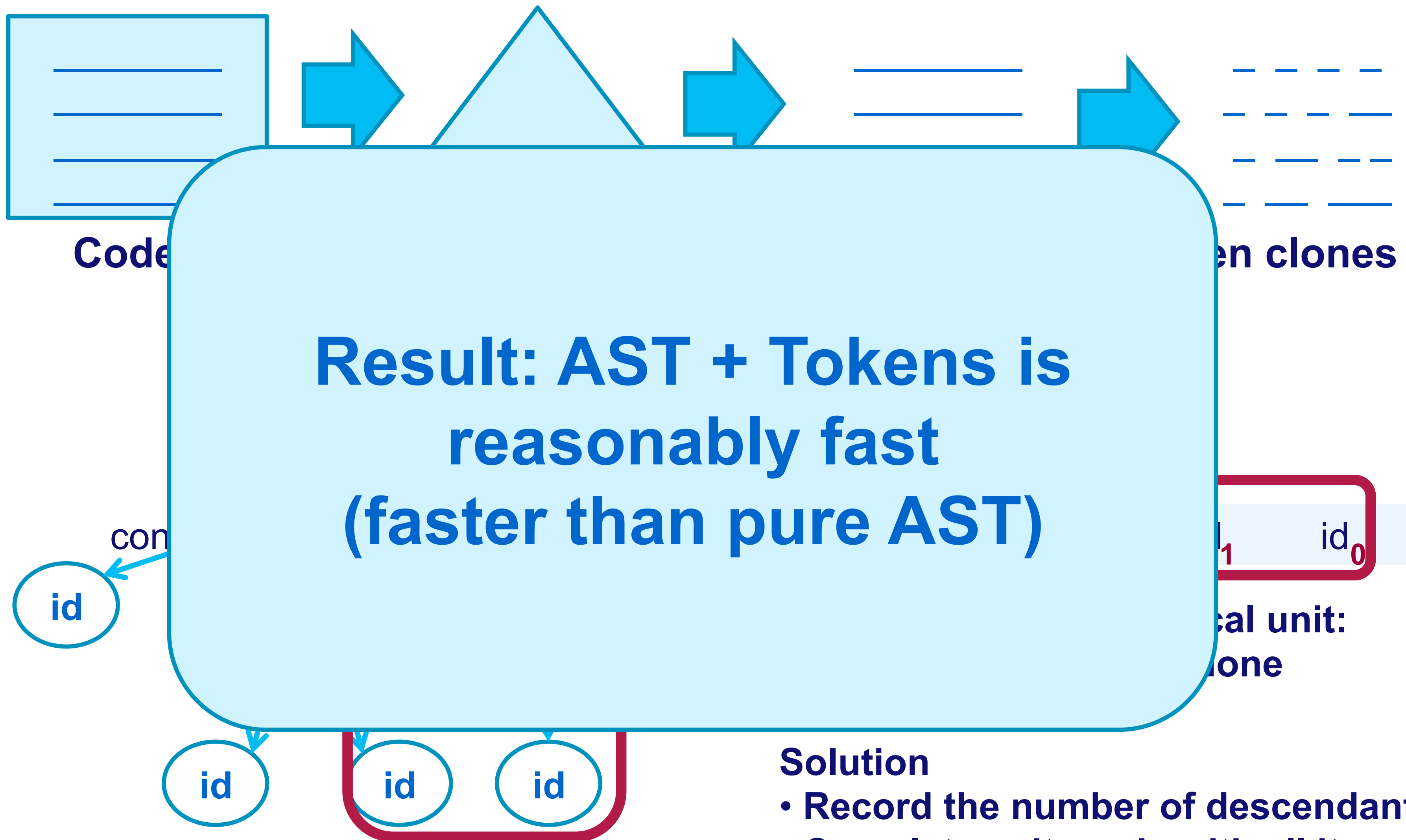
So far…

- [Baker 1995]
  - Token-based
  - Very fast:
    - 1.1 MLOC, minimal clone size: 30 LOC
    - 7 minutes on SGI IRIX 4.1, 40MHz, 256 MB
- [Baxter 1996]
  - AST-based
  - Precise but slow
- Idea: Combine the two! [Koschke et al. 2006]
  - In fact they do not use [Baker 1995] but a different token-based approach

AST + Tokens [Koschke et al. 2006]



Solution

- **Record the number of descendants**
- **Complete unit: node with all its descendants**

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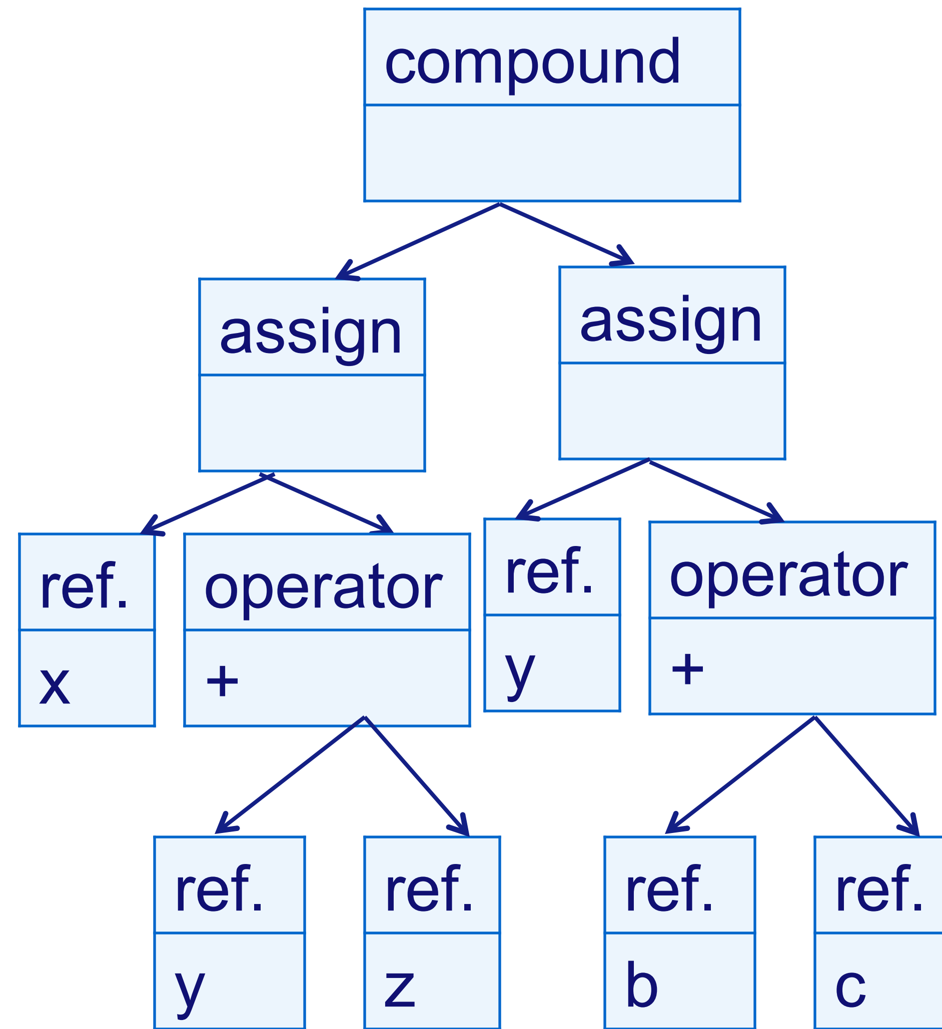
Next step

- AST is a tree is a graph
- There are also other graph representations
  - Object Flow Graph (weeks 3 and 4)
  - UML class/package/… diagrams
  - Program Dependence Graph
- These representations do not depend on textual order
  - { x = 5; y = 7; } vs. { y = 7; x = 5; }

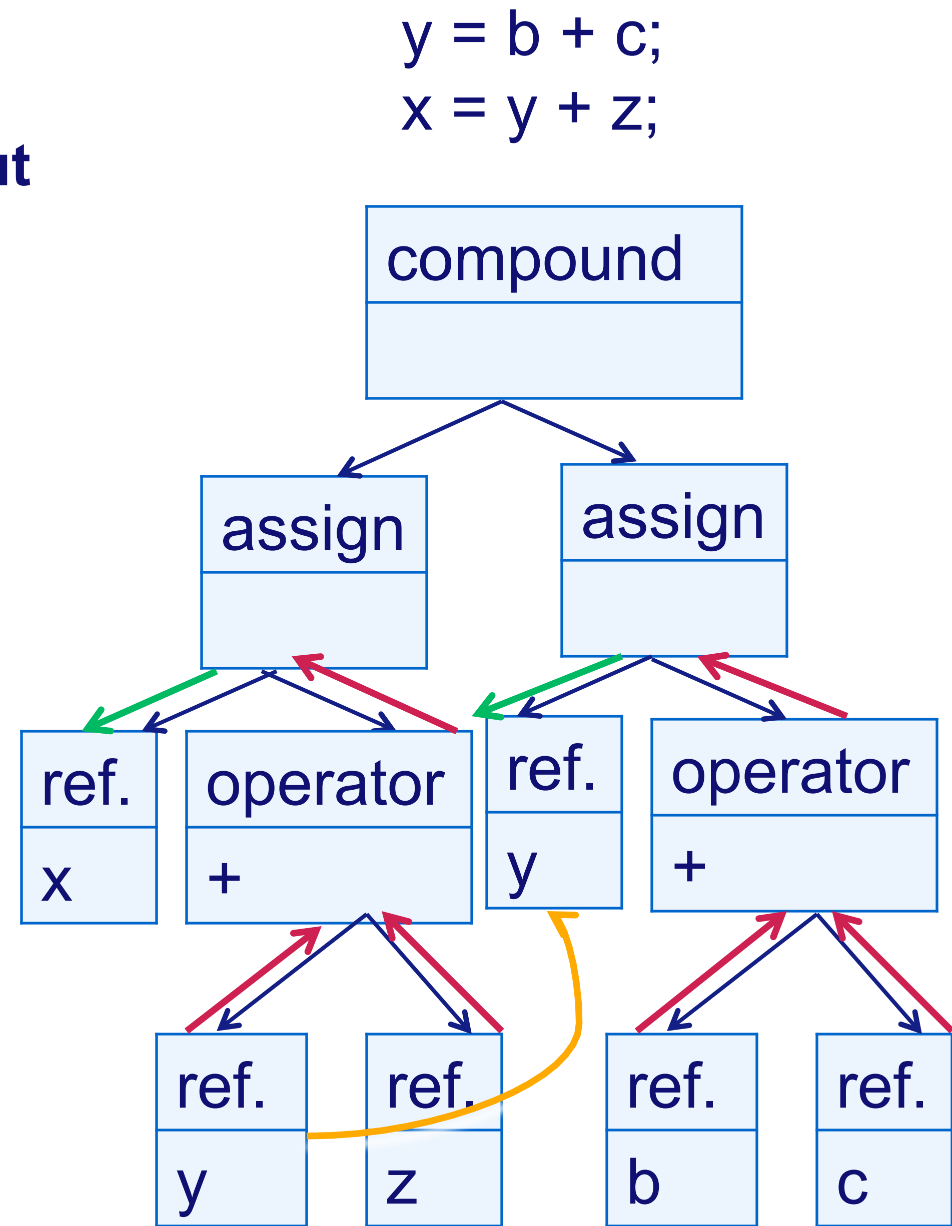
[Krinke 2001] PDG based

- **Vertices:**
  - **entry points, in- and output parameters**
  - **assignments, control statements, function calls**
  - **variables, operators**
- **Edges:**
  - **immediate dependencies**
    - **target has to be evaluated before the source**



[Krinke 2001] PDG based

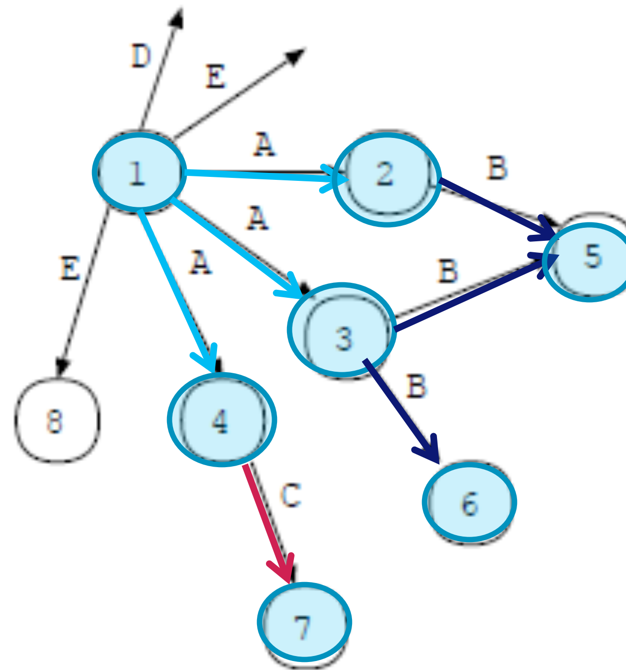
- **Vertices:**
  - entry points, in- and output parameters
  - assignments, control statements, function calls
  - variables, operators
- **Edges:**
  - immediate dependencies
  - value dependencies
  - reference dependencies
  - data dependencies
  - control dependencies
    - Not in this example

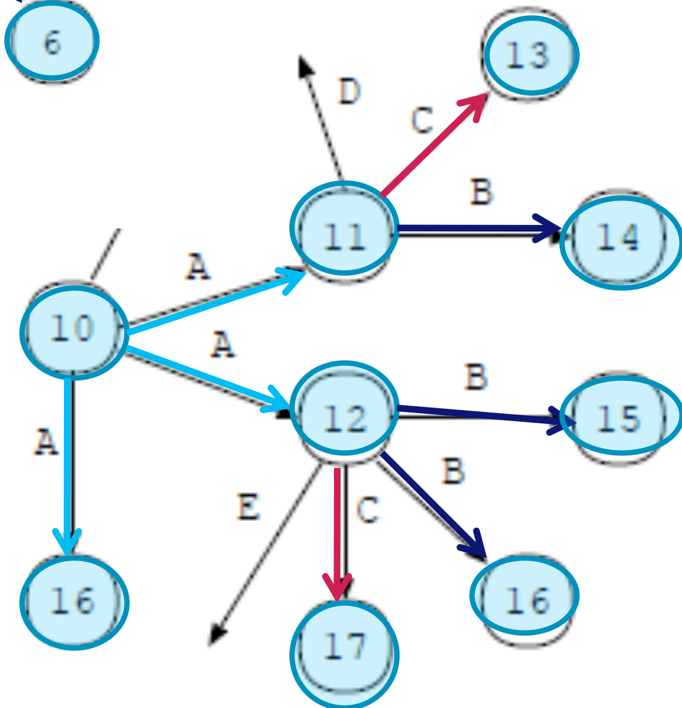


Identification of similar subgraphs – Theory

- **Start with 1 and 10**
- **Partition the incident edges based on their labels**
  - **Select classes present in both graphs**
- **Add the target vertices to the set of reached vertices**
- **Repeat the process**

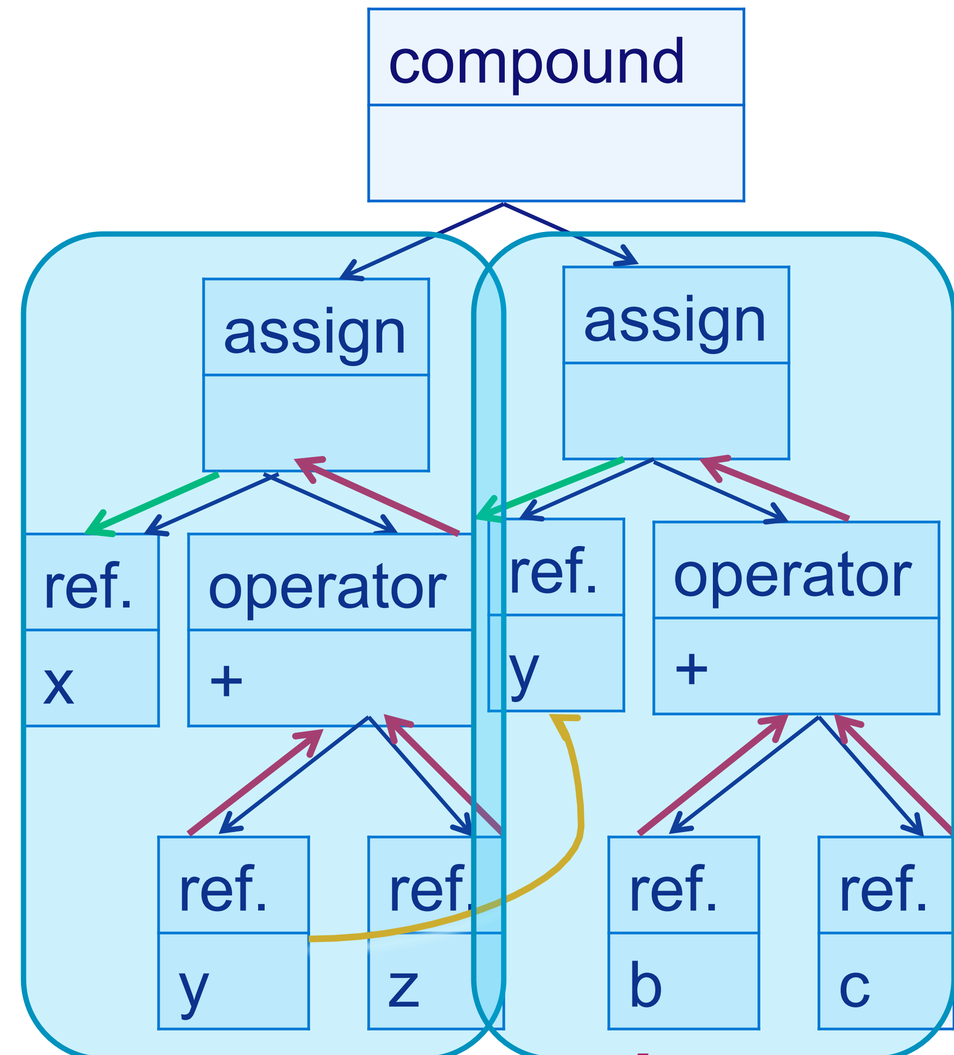
- **"Maximal similar subgraphs"**





Identification of similar subgraphs – Practice

- **Sorts of edges are labels**
- **We also need to compare labels of vertices**
- **We should stop after k iterations**
  - **Higher k ⇒ higher recall**
  - **Higher k ⇒ higher execution time**
  - **Experiment: k = 20**



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Choosing your tools: Precision / Recall

- **Quality depends on scenario [Type 1, Type 2, Type 3]**
- **[Roy *et al.* 2009]: 6 is maximal grade, 0 – minimal**

Tool	Technique	Category	S1	S2	S3
Duploc	Ducasse	Text	4	0	2.8
Marcus and Maletic			2.6	1.8	1.6
Dup	Baker	Token	4	2.8	0
CCFinder	Kamiya		5	3.8	0.8
CloneDr	Baxter	AST	6	4.3	3.8
cpdetector	Koschke		6	3.8	0
Mayrand		Metrics	3.3	4.8	3.4
Duplix	Krinke	Graph	5	4.8	4

More tools: ConQAT, DECKARD, Dude, Simian

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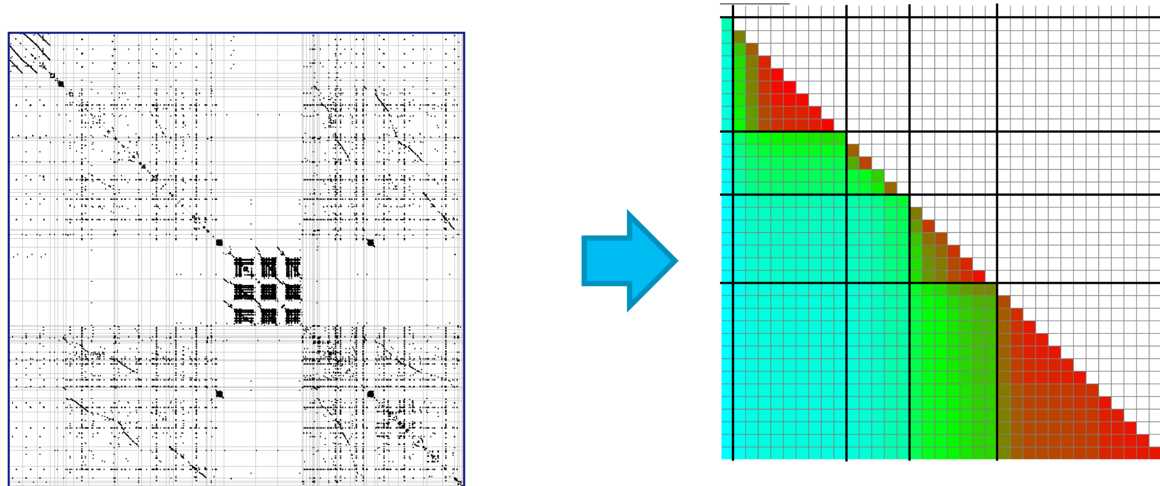
Which technique/tool is the best one?

- Quality
  - Precision
  - Recall
- Usage
  - Availability
  - Dependence on a platform
  - Dependence on an external component (lexer, tokenizer, …)
  - Input/output format
- Programming language
- Clones
  - Granularity
  - Types
  - Pairs vs. groups
- Technique
  - Normalization
  - Storage
  - Worst-case complexity
  - Pre-/postprocessing
- Validation
- *Extra: metrics*

Clones & evolution

- Study clones *between* the versions
- Major version – less similar to the previous one?
- Triangles – stable phase, minor differences



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Clone detection techniques: Summary

- Many different techniques
  - Text, metrics, tokens, AST, program dependence graph, combinations
- Techniques are often supported by tools
- Precision depends on what kind of clones we need:
  - Type 1, Type 2, Type 3, Type 4
- Extra conditions
  - Programming language, presence of external tools, platforms, extra's (metrics), normalization, ...

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