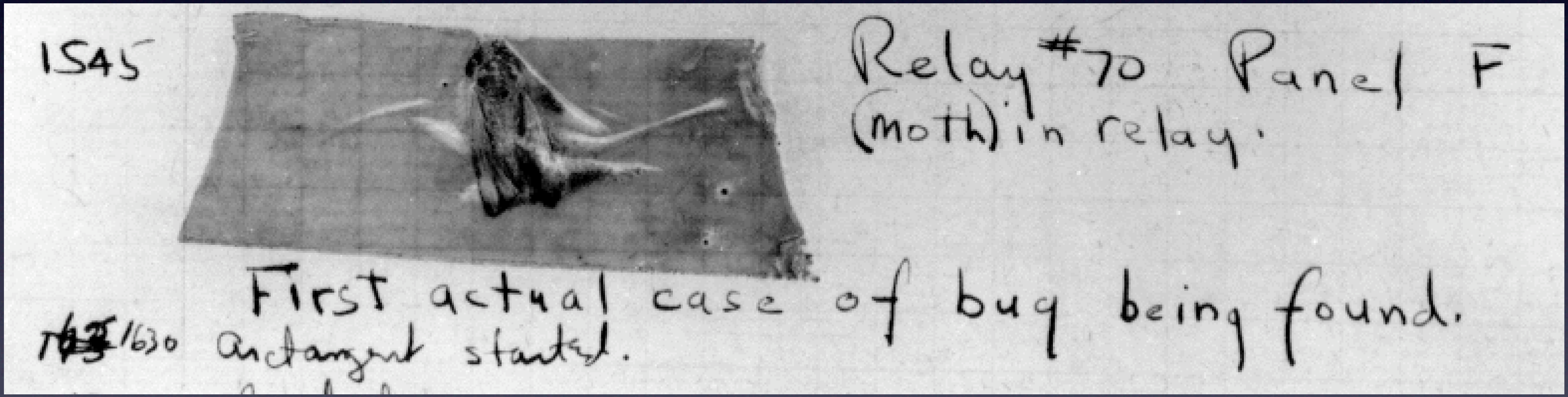
Defect Detection

Thomas Zimmermann

The First Bug

September 9, 1947



More Bugs

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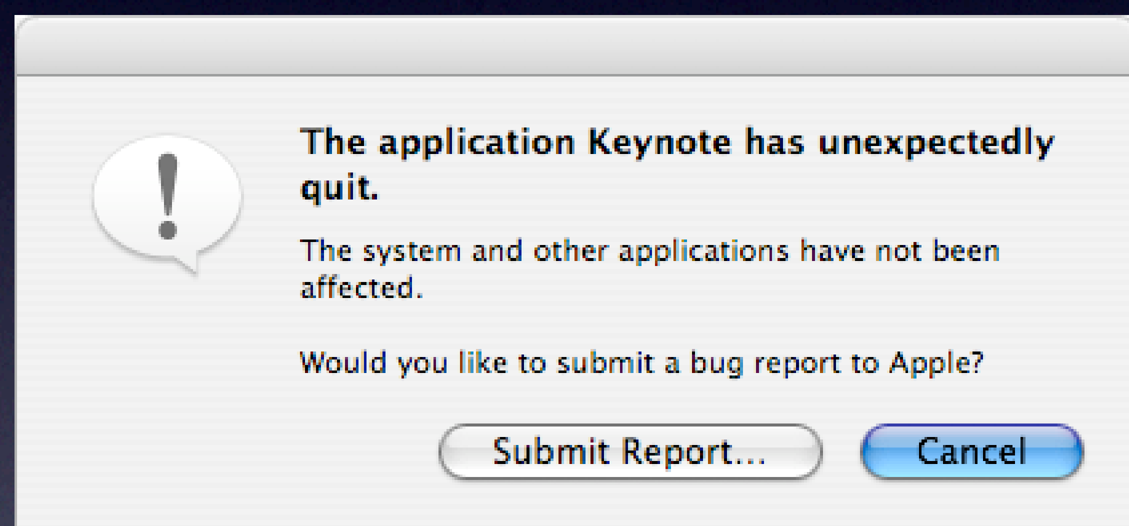
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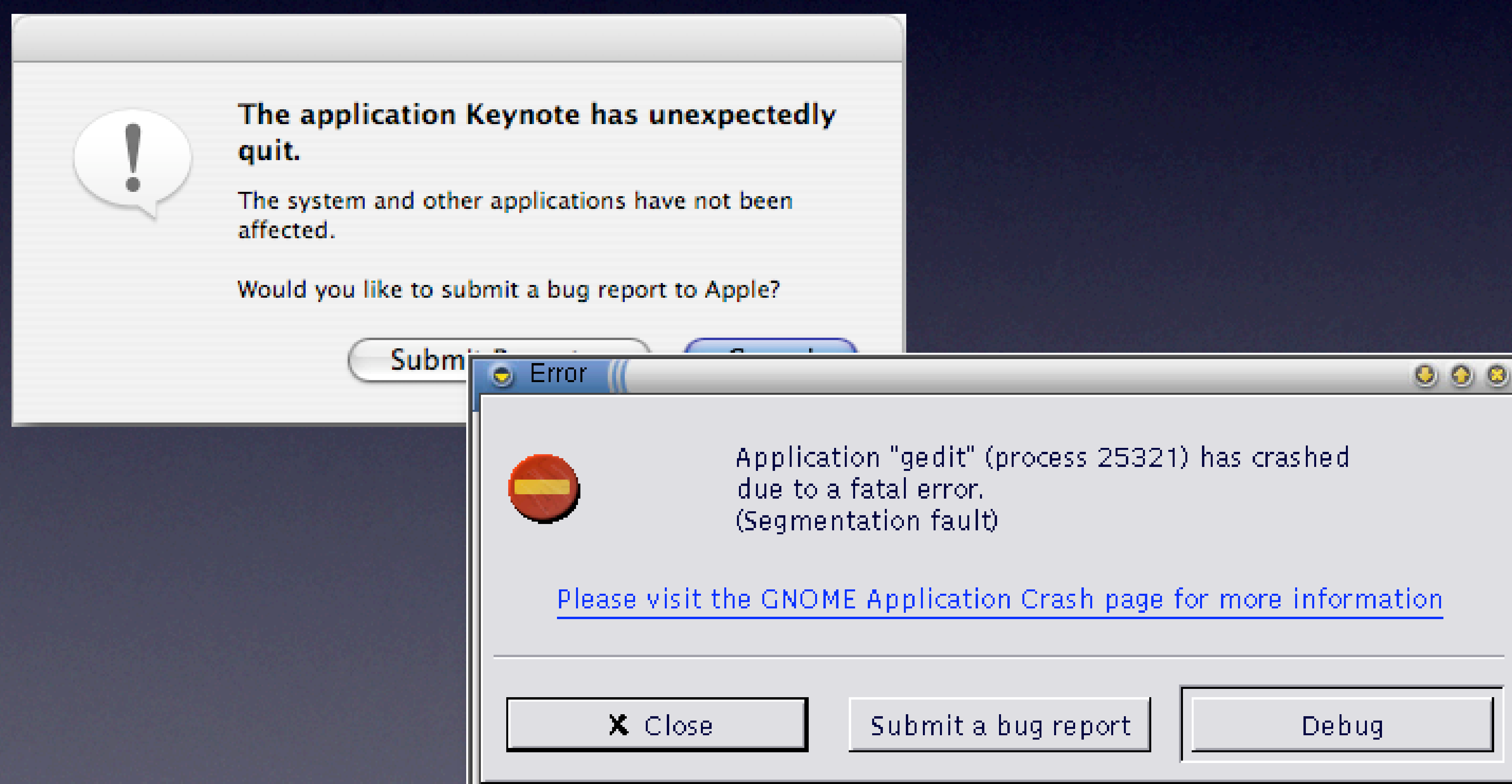
The system and other applications have not been affected.
Would you like to submit a bug report to Apple?
Submit Report...
Cancel

More Bugs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(Segmentation fault)
Please visit the GNOME Application Crash page for more information
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Submit a bug report
Debug

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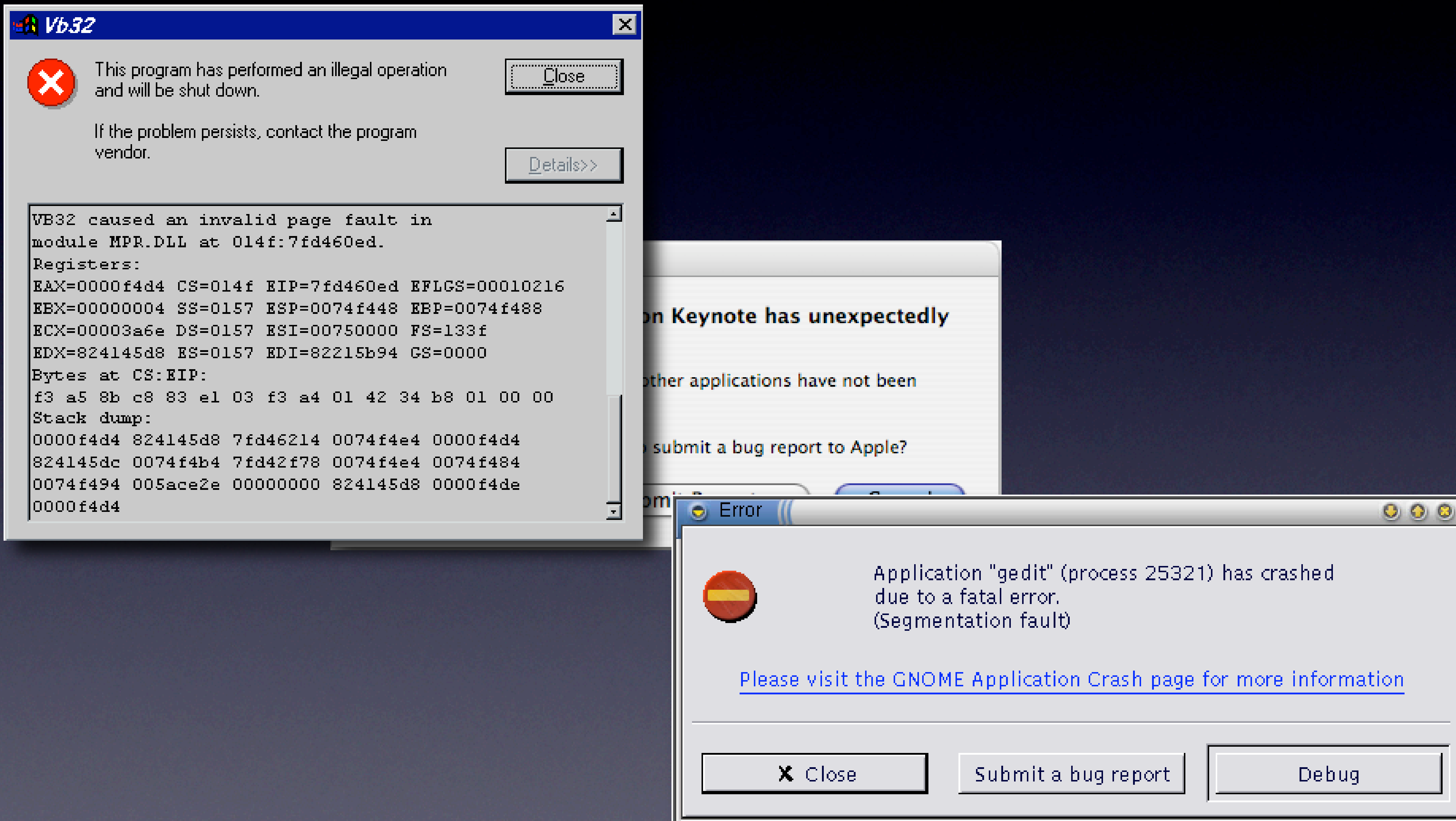
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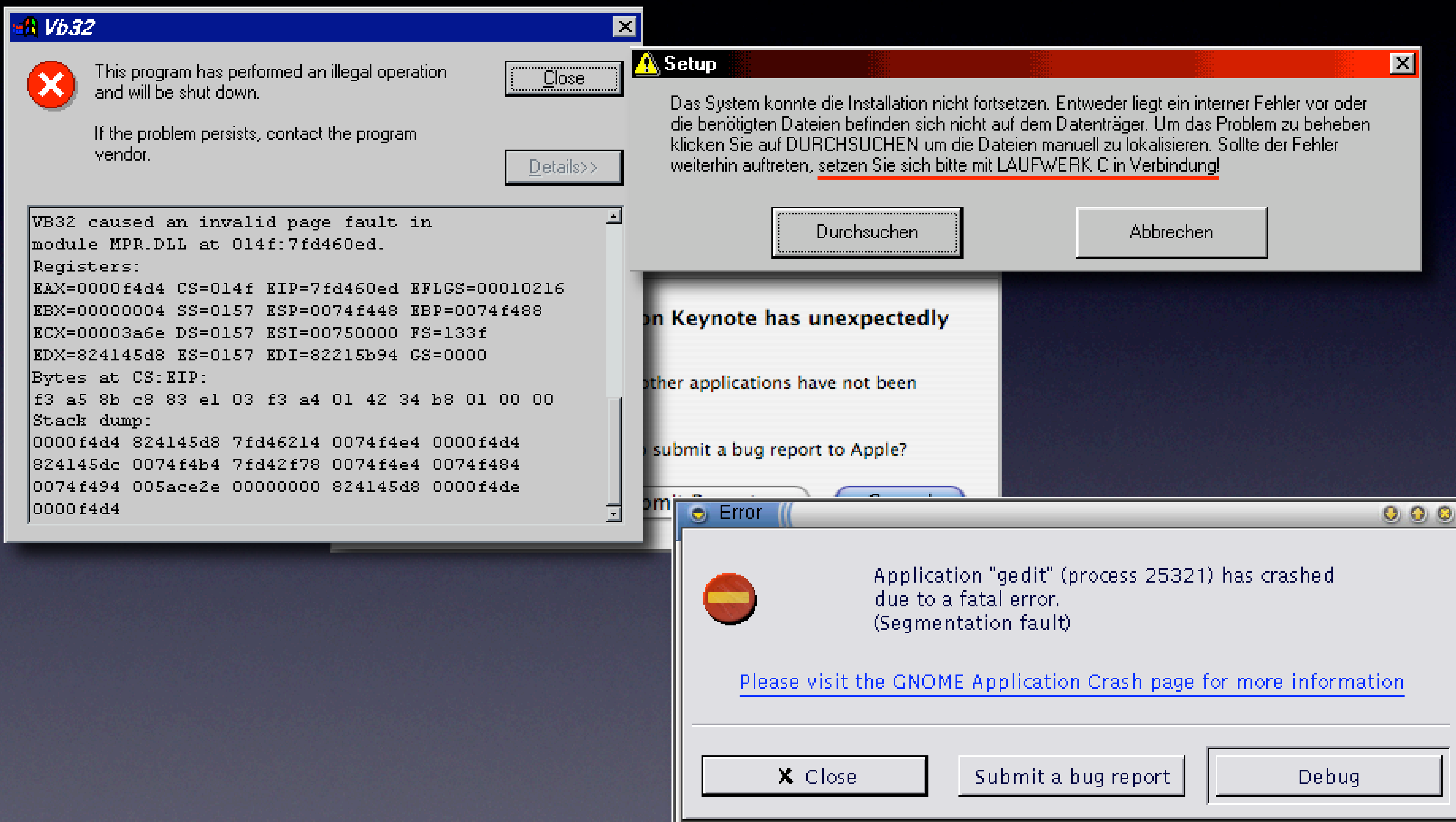
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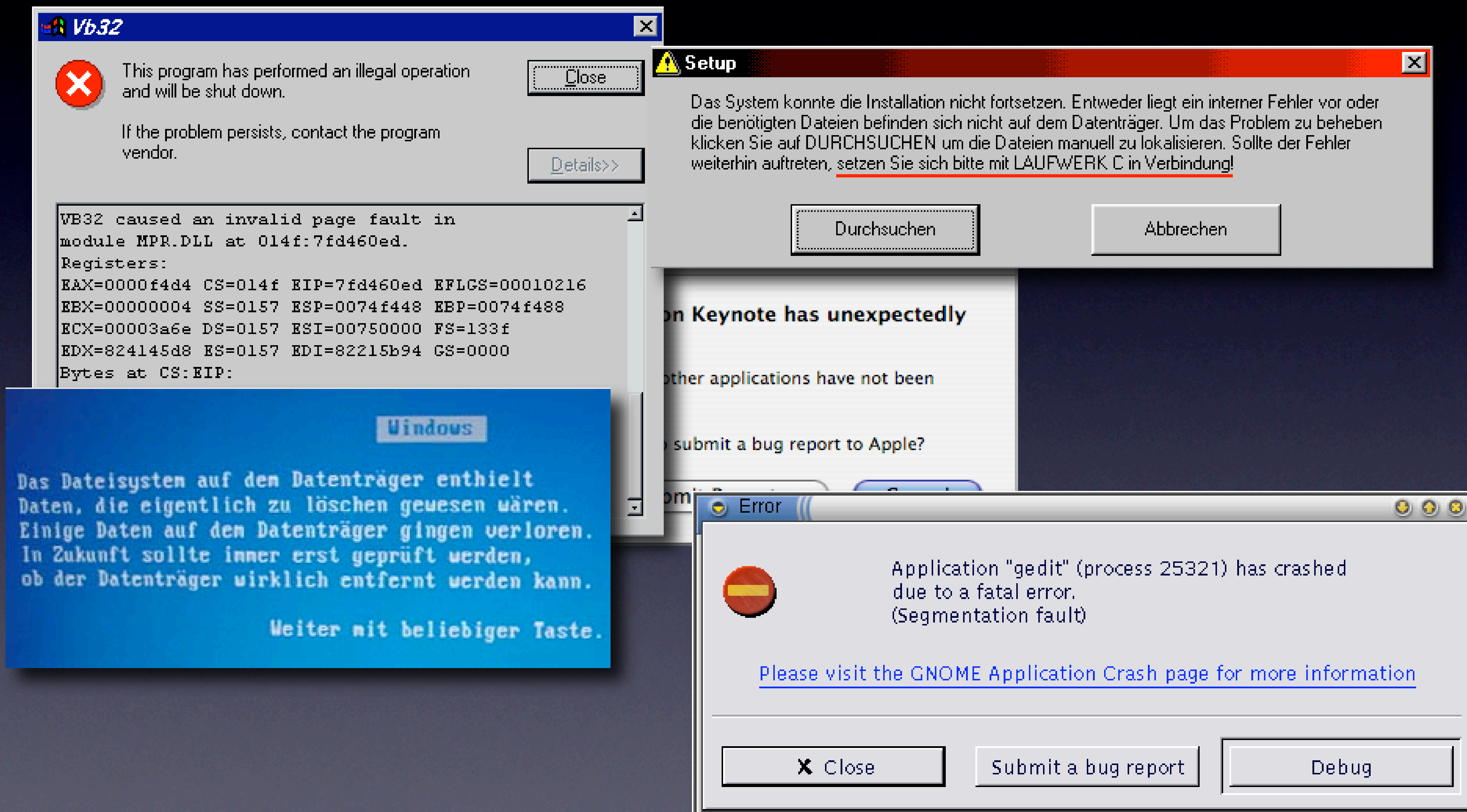
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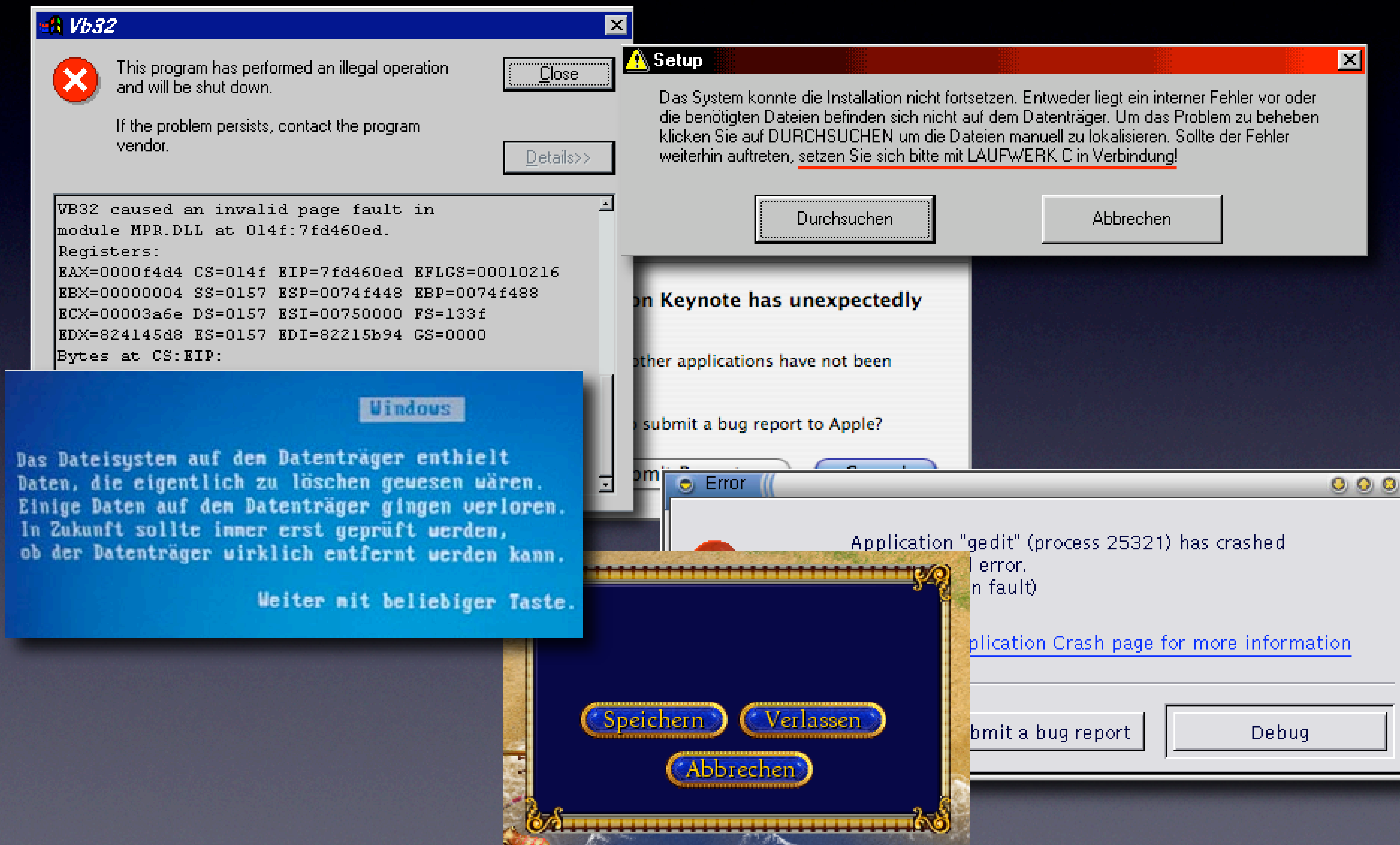

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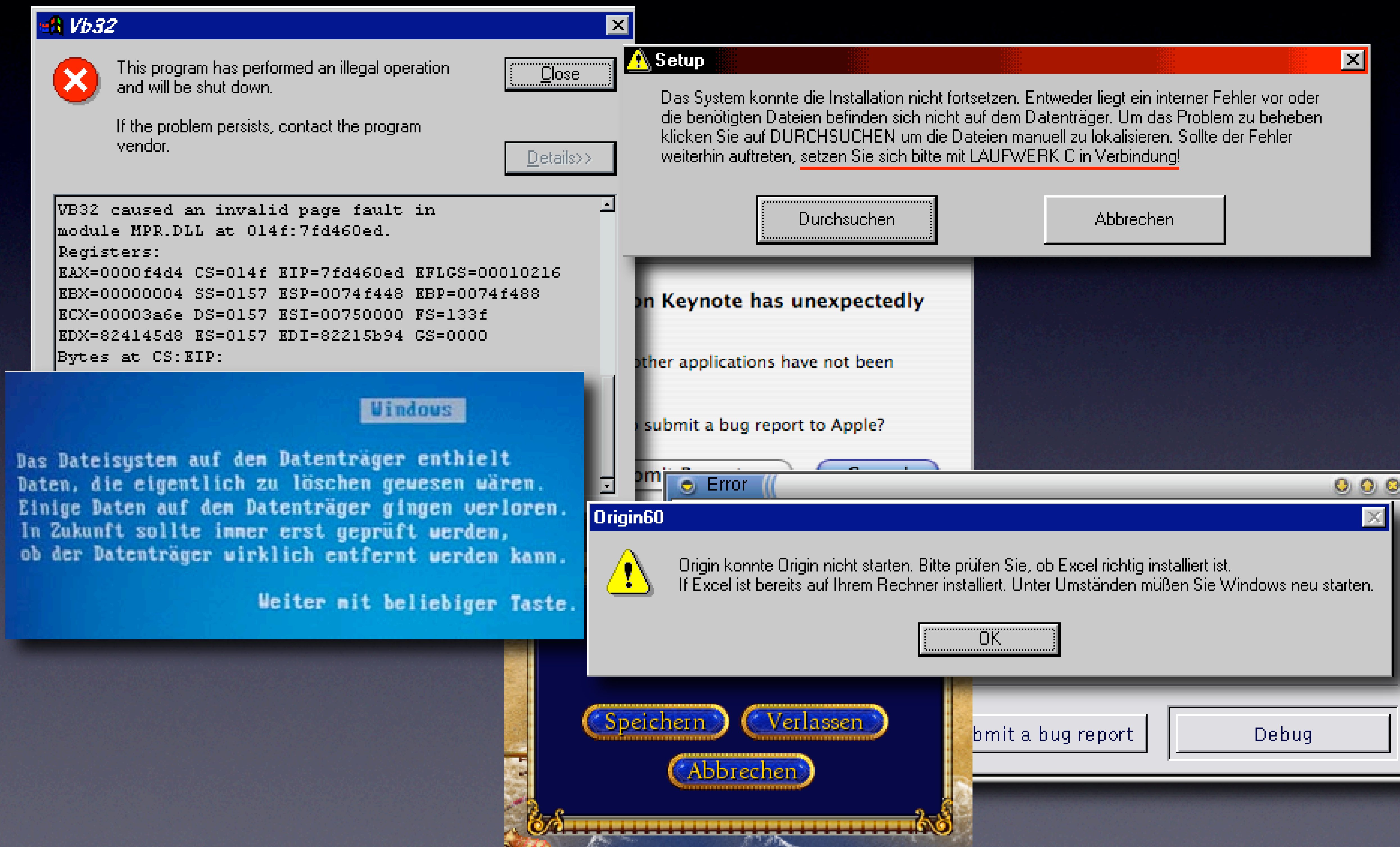
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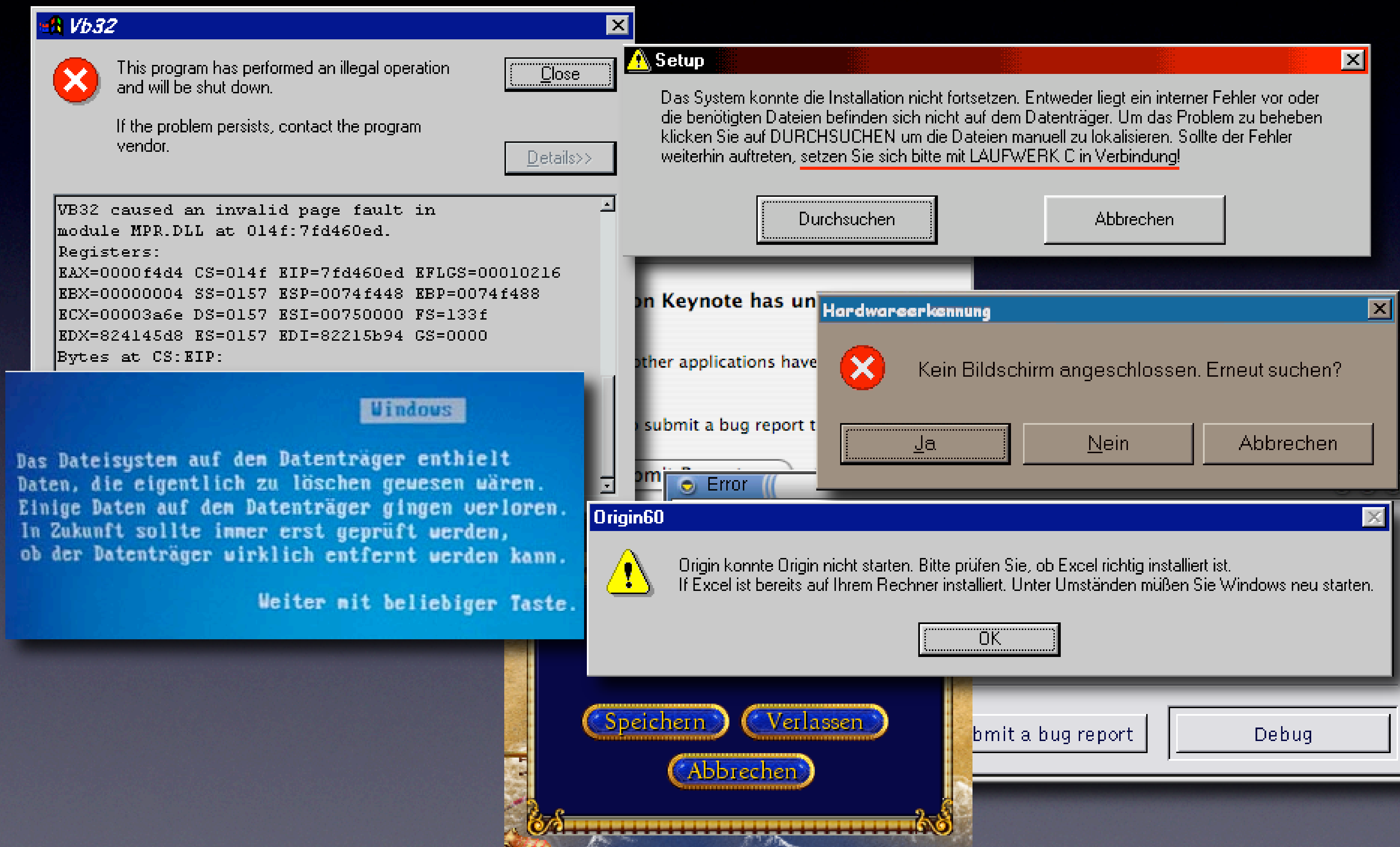

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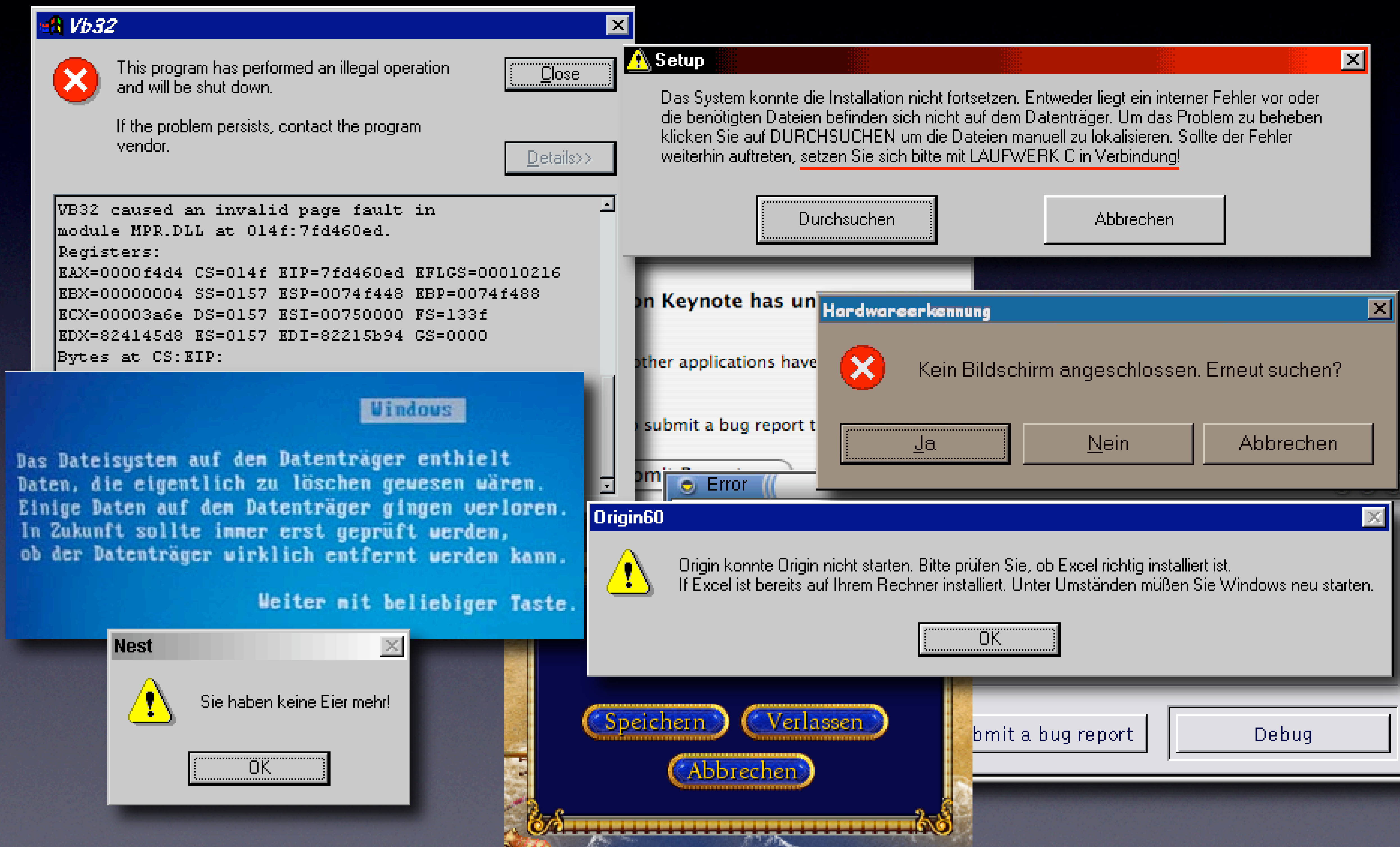
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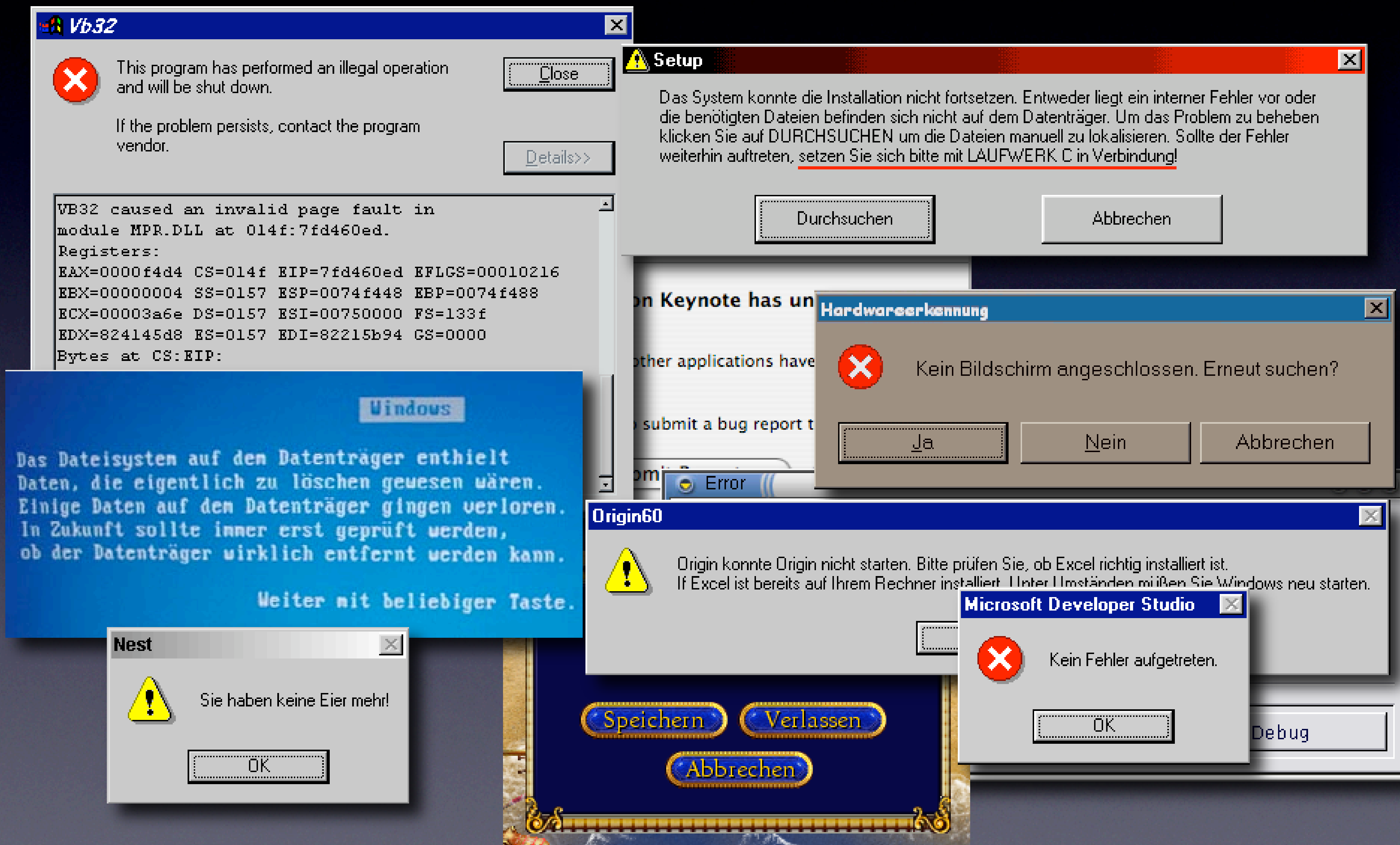
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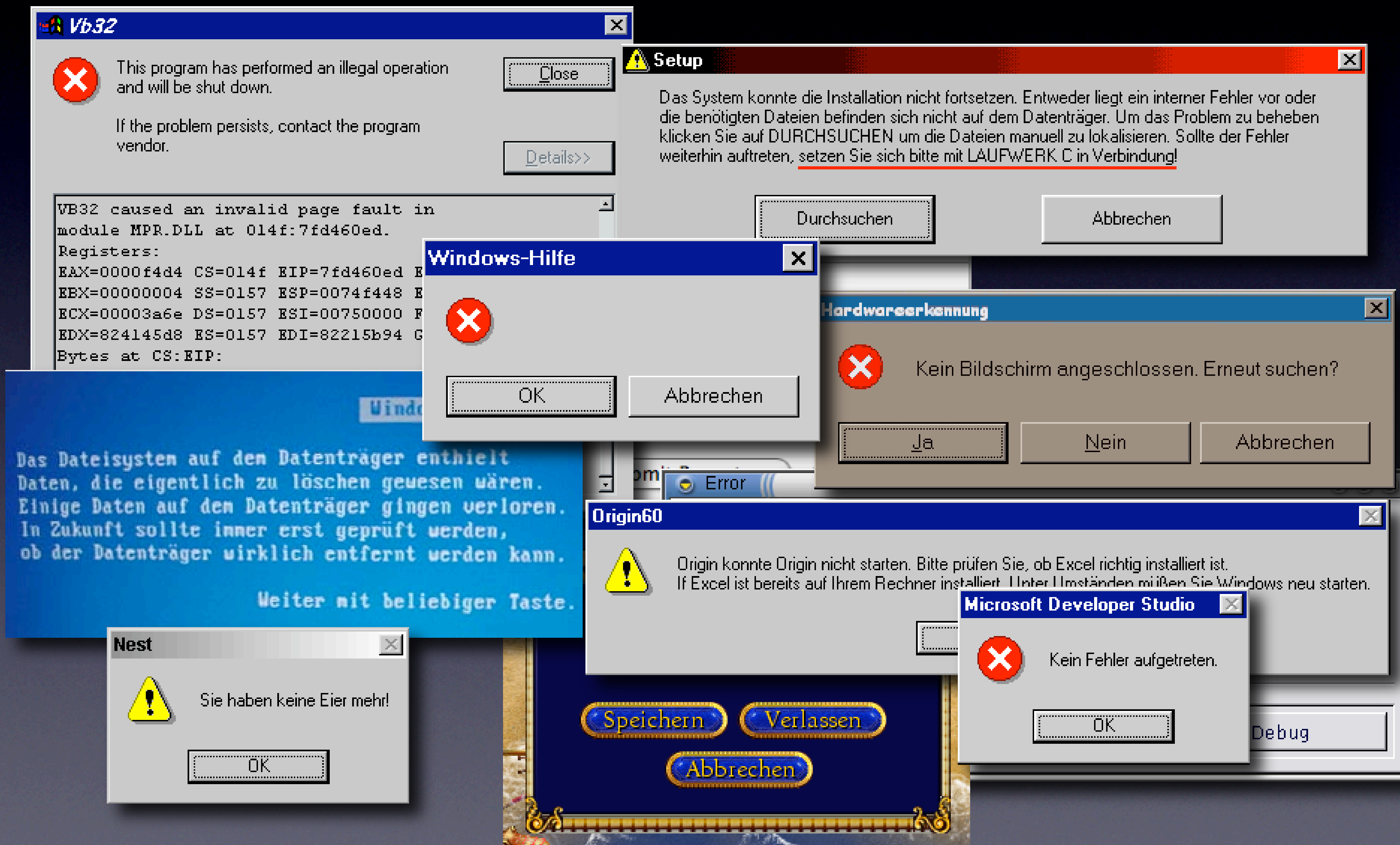

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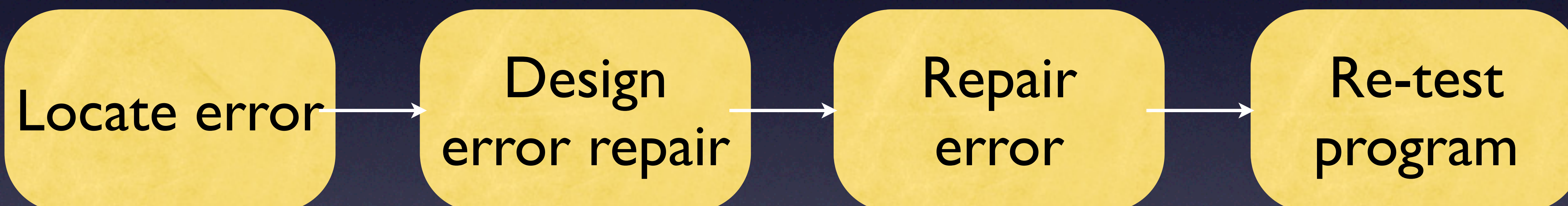
Facts on Debugging

- Software bugs are costing ~60 bln US$/yr
- Improvements could reduce cost by 30%
- Validation (including debugging) can easily take up to 50-75% of the development time
- When debugging, some people are three times as efficient than others

How to Debug

(Sommerville 2004)



The Traffic Principle

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The Traffic Principle

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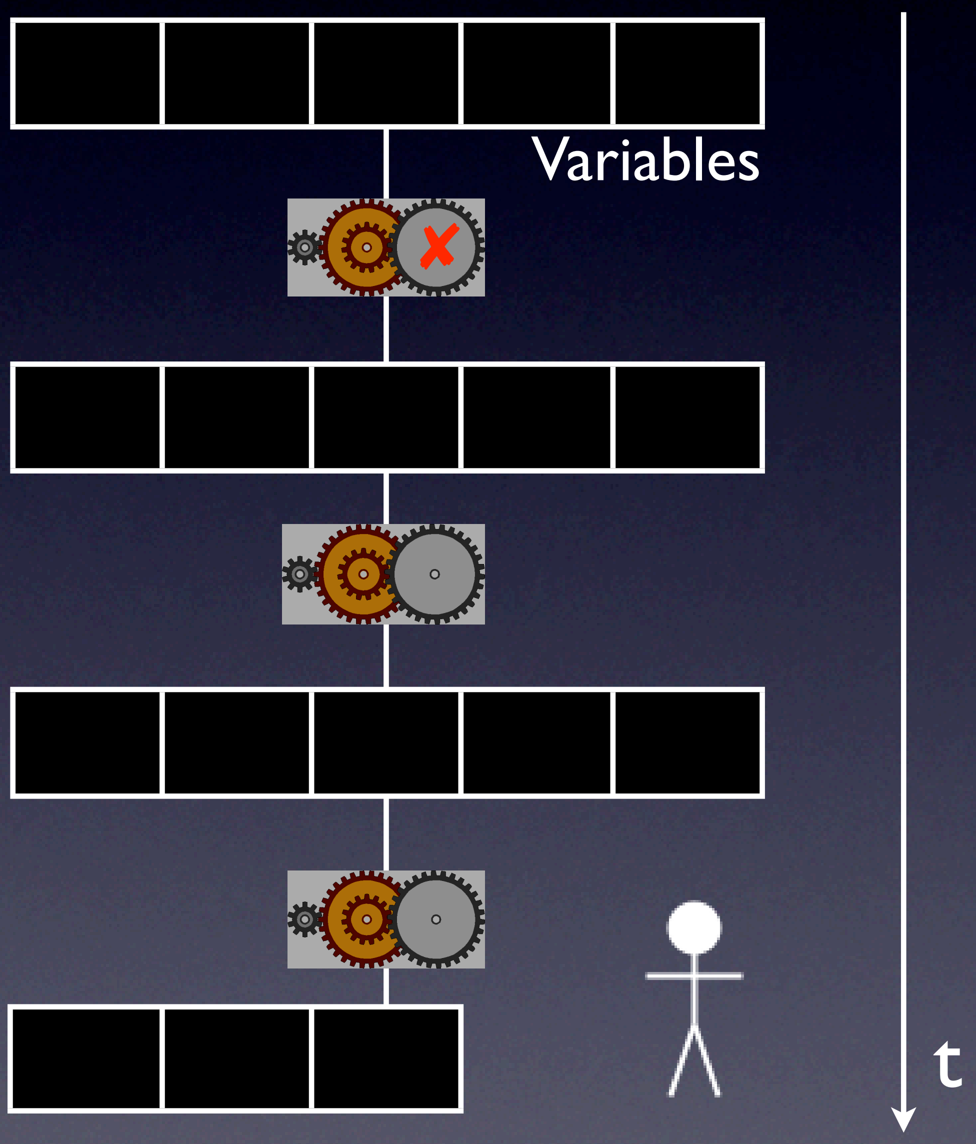
From Defect to Failure

1. The programmer creates a *defect* – an error in the code.
2. When executed, the defect creates an *infection* – an error in the state.
3. The infection *propagates*.
4. The infection causes a *failure*.



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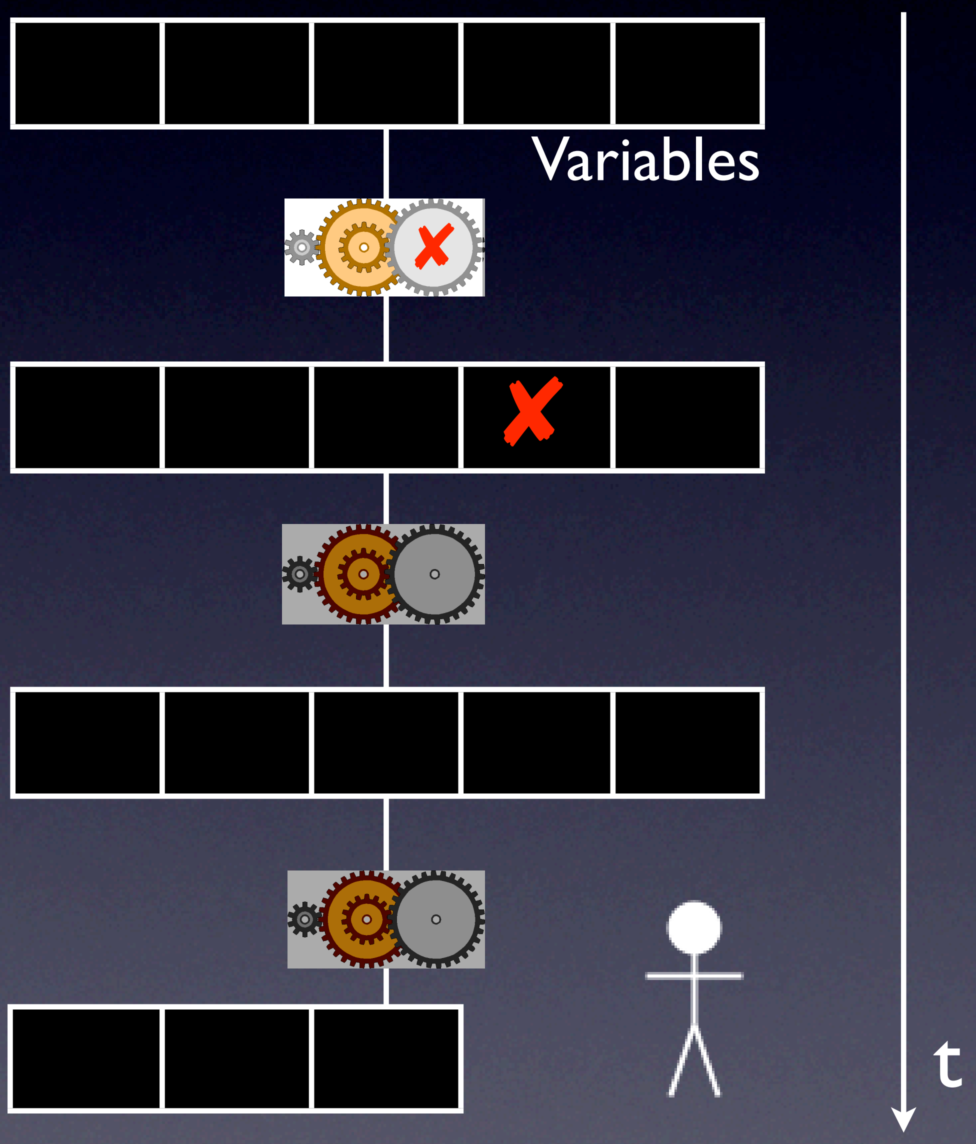

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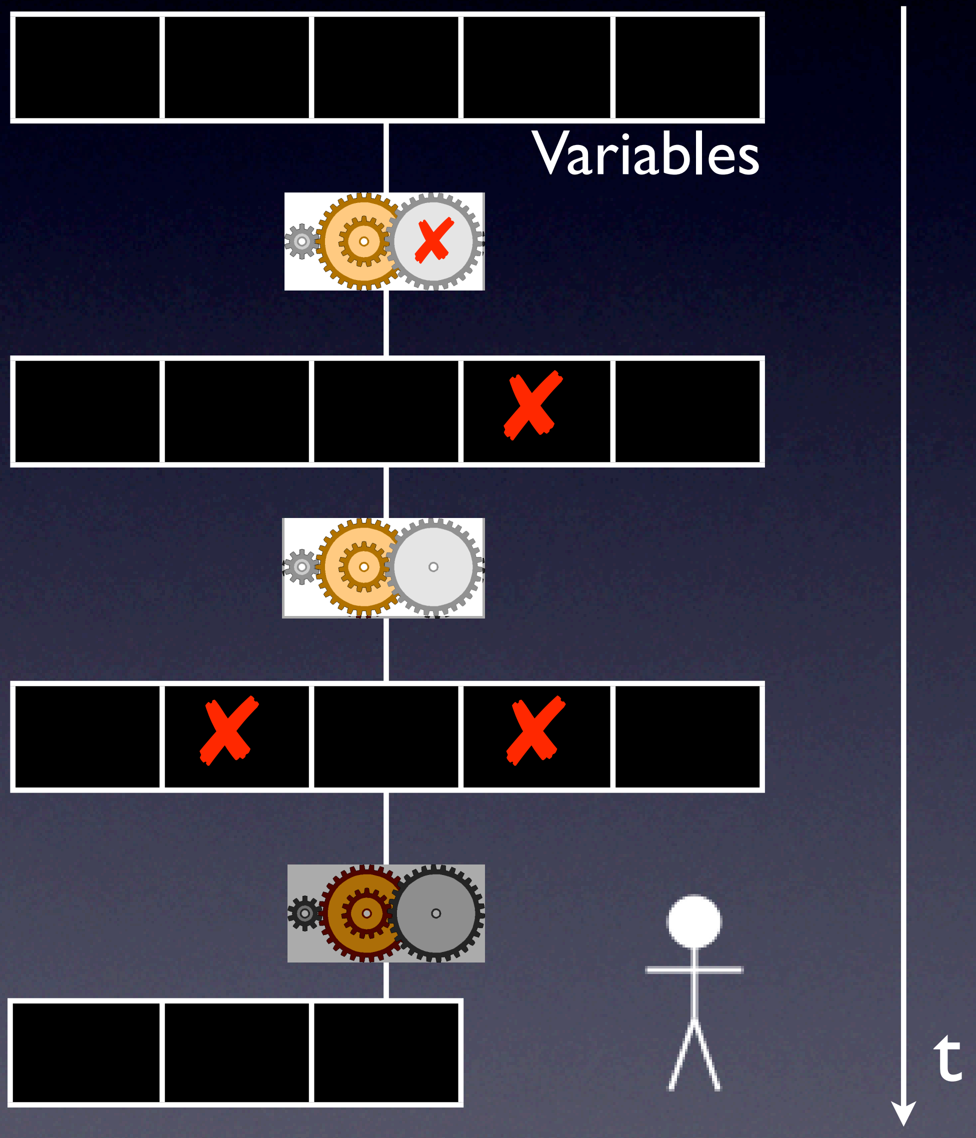

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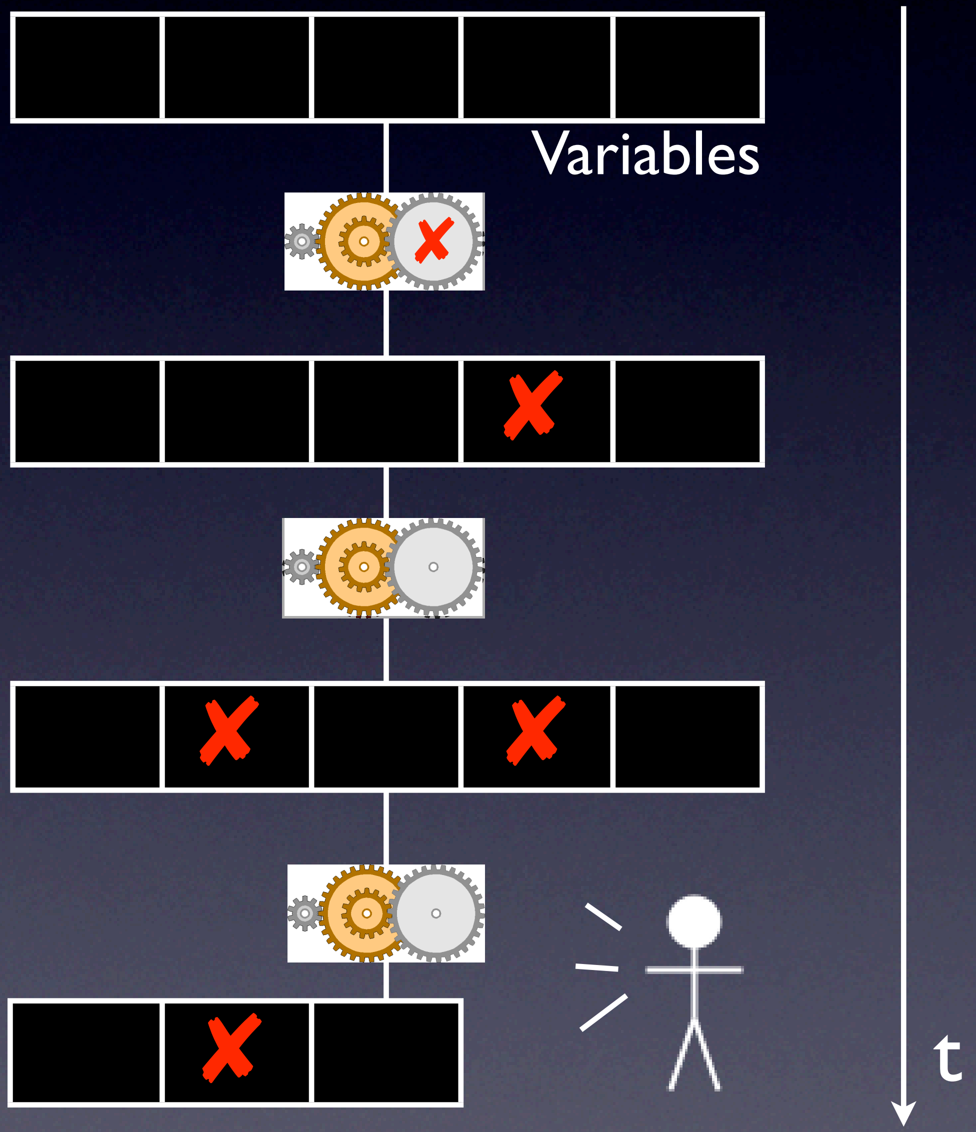

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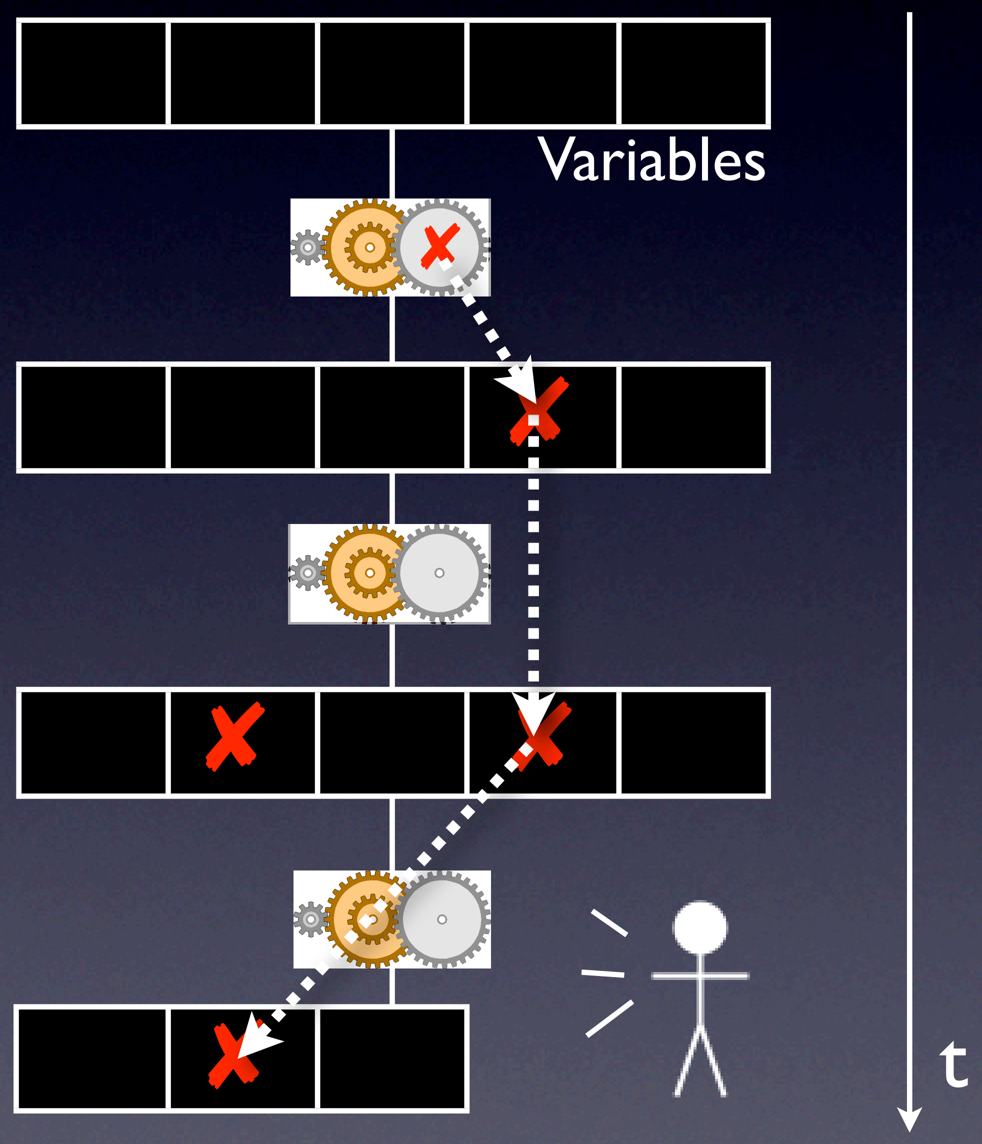
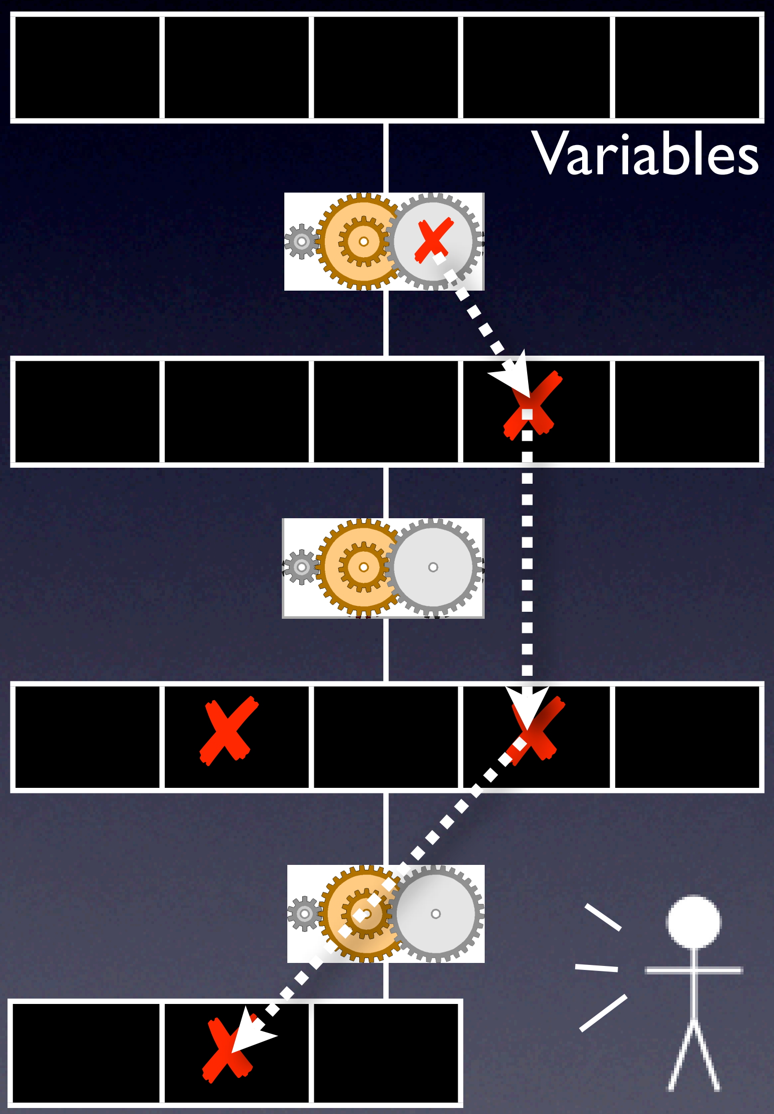
This infection chain must be traced back – and broken.



The Curse of Testing

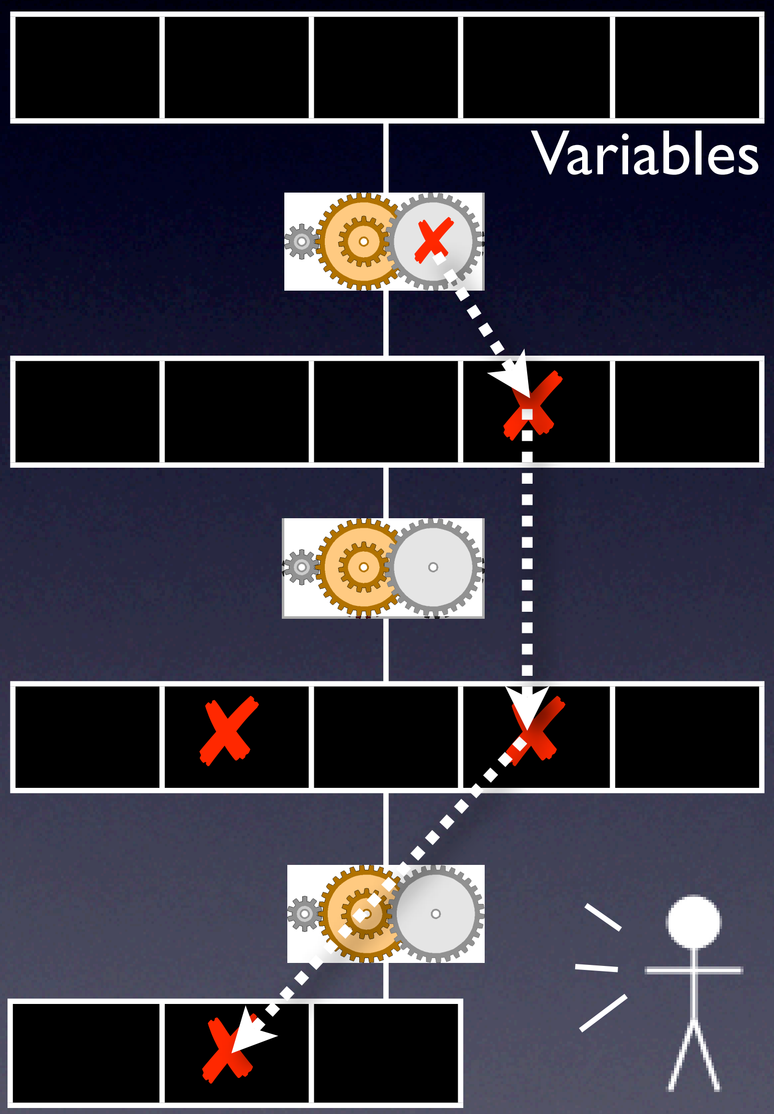
- Not every defect causes a failure!
- *Testing can only show the presence of errors – not their absence.*

  (Dijkstra 1972)

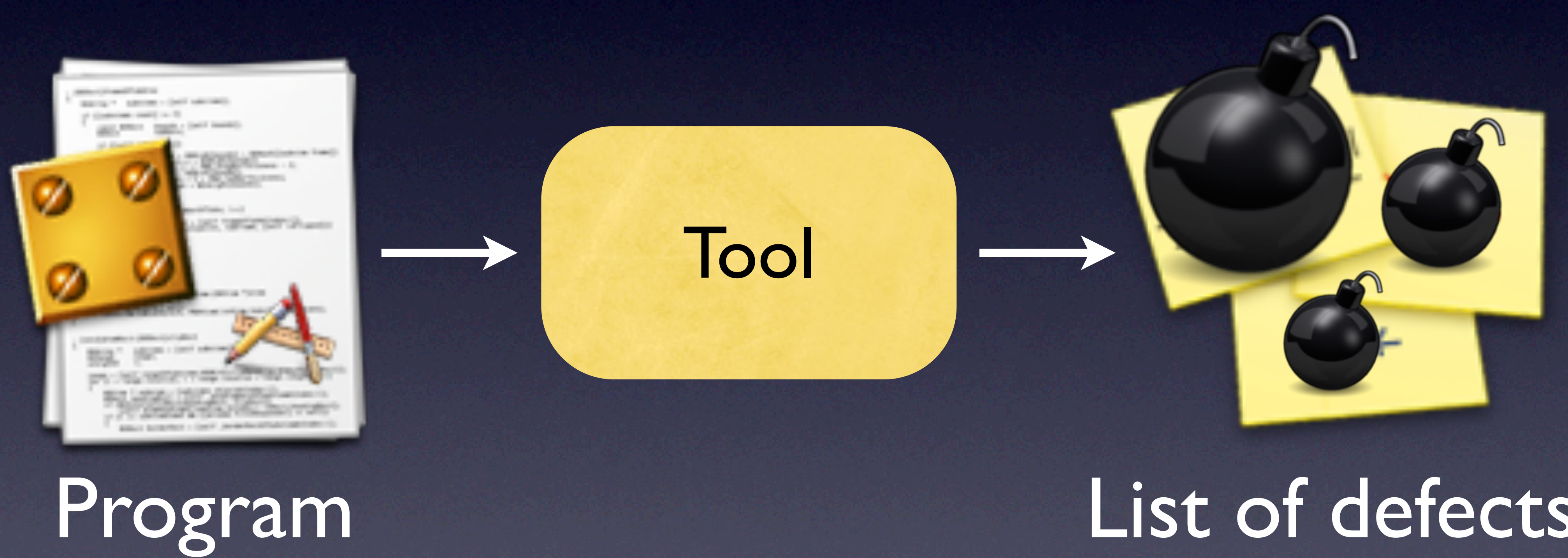


Debugging

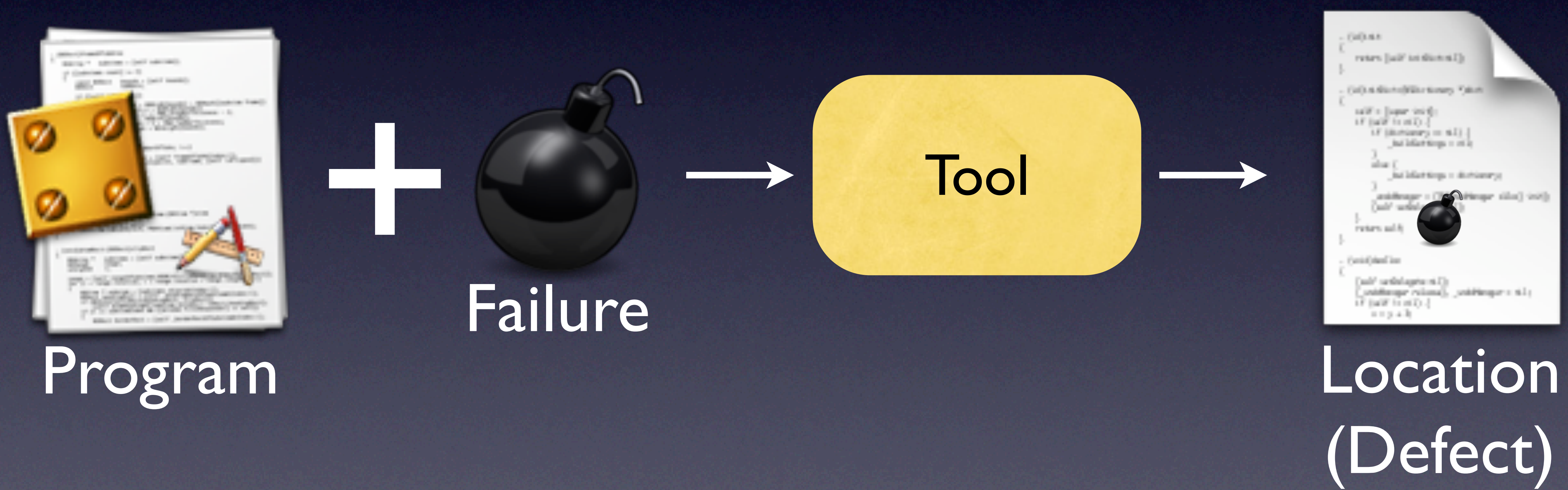
- Every *failure* can be traced back to some *infection*, and every *infection* is caused by some *defect*.
- *Debugging* means to *relate a given failure to the defect* – and to remove the defect.



Defect detection



Defect localization



Outline

Redundancies (Engler et al.)	FindBugs (Pugh et al.)
Models (Invited talk: A. Wasylkowski)	Statistical (Liblit et al.)

Dawson Engler

Co-founder of Coverity

redundancies
flag errors

Idempotent operations

Flag idempotent operations.

- variable is assigned to itself: x=x
- variable is divided by itself: x/x
- variable is bitwise or'd with itself: x|x
- variable is bitwise and'd with itself: x&x

Idempotent operations

/* 2.4.1/net/appletalk/aarp.c:aarp_rcv */

```
...
else { /* We need to make a copy of the entry. */
  da.s_node = sa.s_node;
  da.s_net = da.s_net;
  ...
```

System	Bugs	Minor	False
Linux	7	6	3

Redundant assignments

Flag cases where a value assigned to a variable is subsequently not used.

System	Bugs	False	Uninspected
Linux	129	26	1840
xgcc	13	1	0

Redundant assignments

/* 2.4.1/net/decnet/af_decnet.c:dn_wait_run */

```
do {
  ...
  if (signal_pending(current)) {
     err = -ERESTARTSYS;
     break;
  }
  SOCK_SLEEP_PRE(sk)
  if (scp->state != DN_RUN)
       schedule();
  SOCK_SLEEP_POST(sk)
} while(scp->state != DN_RUN);
return 0;
```

Redundant assignments

/* 2.4.1/net/decnet/af_decnet.c:dn_wait_run */

```
do {
  ...
  if (signal_pending(current)) {
     err = -ERESTARTSYS; /* BUG: lost value */
     break;
  }
  SOCK_SLEEP_PRE(sk)
  if (scp->state != DN_RUN)
       schedule();
  SOCK_SLEEP_POST(sk)
} while(scp->state != DN_RUN);
return 0;
```

Unintentionally discarded

Redundant assignments

/* 2.4.1/net/atm/lec.c:lec_addr_delete: */

```
for(entry=priv->lec_arp_tables[i];
    entry != NULL;
    entry=next) {
  next = entry->next;
  if (...) {
      lec_arp_remove(priv->lec_arp_tables, entry);
      kfree(entry);
  }
  lec_arp_unlock(priv);
  return 0;
}
```

Redundant assignments

/* 2.4.1/net/atm/lec.c:lec_addr_delete: */

```
for(entry=priv->lec_arp_tables[i];
    entry != NULL;
    entry=next) { /* BUG: never reached */
  next = entry->next;
  if (...) {
      lec_arp_remove(priv->lec_arp_tables, entry);
      kfree(entry);
  }
  lec_arp_unlock(priv);
  return 0;
}
```

Surprising control flow

Dead code

Flag dead code (i.e., code that is never executed).

System	Bugs	False
Linux	66	26

Dead code

/* 2.4.5-ac8/fs/ntfs/unistr.c:ntfs_collate_names */

```
for (cnt = 0; cnt < min(name1_len, name2_len); ++cnt) {
   c1 = le16_to_cpu(*name1++);
   c2 = le16_to_cpu(*name2++);
   if (ic) {
       if (c1 < upcase_len)
           c1 = le16_to_cpu(upcase[c1]);
       if (c2 < upcase_len)
           c2 = le16_to_cpu(upcase[c2]);
   }

   if (c1 < 64 && legal_ansi_char_array[c1] & 8);
       return err_val;
   if (c1 < c2)
       return -1;
   ...
```

Dead code

```
/* 2.4.5-ac8/fs/ntfs/unistr.c:ntfs_collate_names */
for (cnt = 0; cnt < min(name1_len, name2_len); ++cnt) {
   c1 = le16_to_cpu(*name1++);
   c2 = le16_to_cpu(*name2++);
   if (ic) {
       if (c1 < upcase_len)
           c1 = le16_to_cpu(upcase[c1]);
       if (c2 < upcase_len)
           c2 = le16_to_cpu(upcase[c2]);
   }
   /* [META] stray terminator! */
   if (c1 < 64 && legal_ansi_char_array[c1] & 8);
       return err_val;
   if (c1 < c2)
       return -1;
   ...
```

Redundant conditionals

Flag redundant branch conditionals from
(1) branch statements with non-constant conditionals that always evaluate to either true or false
(2) switch statements with impossible cases

System	Bugs	False	Uninspected
Linux	49	52	169

Redundant conditionals

/* 2.4.1/drivers/fc/iph5526.c:rscn_handler */

```
if ((login_state == NODE_LOGGED_IN) ||
    (login_state == NODE_PROCESS_LOGGED_IN)) {
    ...
}
else
if (login_state == NODE_LOGGED_OUT)
    tx_adisc(fi, ELS_ADISC, node_id,
             OX_ID_FIRST_SEQUENCE);
else /* BUG: redundant conditional */
if (login_state == NODE_LOGGED_OUT)
    tx_logi(fi, ELS_PLOGI, node_id);
```

Redundant conditionals

/* 2.4.1/drivers/fc/iph5526.c:rscn_handler */

```
if ((logi
    (logi
    ...
}
else
if (login
    tx_ad
          OX_ID_FIRST_SEQUENCE);
else /* B
if (login
    tx_lo
```

Overly cautious programming style (confused programmer)

Single iteration loop

Cut-and-paste errors

Correlation to hard bugs

Hard bugs can crash a system (use of freed memory, dereferences of null pointers, potential deadlocks, unreleased locks, and security violations)

A	B: True	B: False	Totals
True	o_{11}	o_{12}	$n_{1\cdot}$
False	o_{21}	o_{22}	$n_{2\cdot}$
Totals	$n_{\cdot 1}$	$n_{\cdot 2}$	$n_{\cdot\cdot}$

Chi-Square test

Null hypothesis: "A and B are mutually independent"

Correlation to hard bugs

Redundant Assignments	Hard Bugs Yes	Hard Bugs No	Totals
Yes	345	435	780
No	206	1069	1275
Totals	551	1504	2055

$T = 194.37$, p-value $= 0.00$

Correlation to hard bugs

Redundant Assignments	Hard Bugs Yes	Hard Bugs No	Totals
Yes	345	435	780
No	206	1069	1275
Totals	551	1504	2055

$T = 194.37$, p-value $= 0.00$

dependant

Correlation to hard bugs

Redundant Assignments	Hard Bugs Yes	Hard Bugs No	Totals
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Totals	551	1504	2055

$T = 194.37$, p-value $= 0.00$

dependant

Redundant Conditionals	Hard Bugs Yes	Hard Bugs No	Totals
Yes	75	79	154
No	476	1425	1901
Totals	551	1504	2055

$T = 40.65$, p-value $= 0.00$

dependant

Correlation to hard bugs

Redundant Assignments	Hard Bugs Yes	Hard Bugs No	Totals
Yes	345	435	780
No	206	1069	1275
Totals	551	1504	2055

$T = 194.37$, p-value $= 0.00$

dependant

Redundant Conditionals	Hard Bugs Yes	Hard Bugs No	Totals
Yes	75	79	154
No	476	1425	1901
Totals	551	1504	2055

$T = 40.65$, p-value $= 0.00$

dependant

Dead Code	Hard Bugs Yes	Hard Bugs No	Totals
Yes	133	135	268
No	418	1369	1787
Totals	551	1504	2055

$T = 81.74$, p-value $= 0.00$

dependant

Correlation to hard bugs

Redundant Assignments	Hard Bugs Yes	Hard Bugs No	Totals
Yes	345	435	780
No	206	1069	1275
Totals	551	1504	2055

$T = 194.37$, p-value $= 0.00$

dependant

Redundant Conditionals	Hard Bugs Yes	Hard Bugs No	Totals
Yes	75	79	154
No	476	1425	1901
Totals	551	1504	2055

$T = 40.65$, p-value $= 0.00$

dependant

Dead Code	Hard Bugs Yes	Hard Bugs No	Totals
Yes	133	135	268
No	418	1369	1787
Totals	551	1504	2055

$T = 81.74$, p-value $= 0.00$

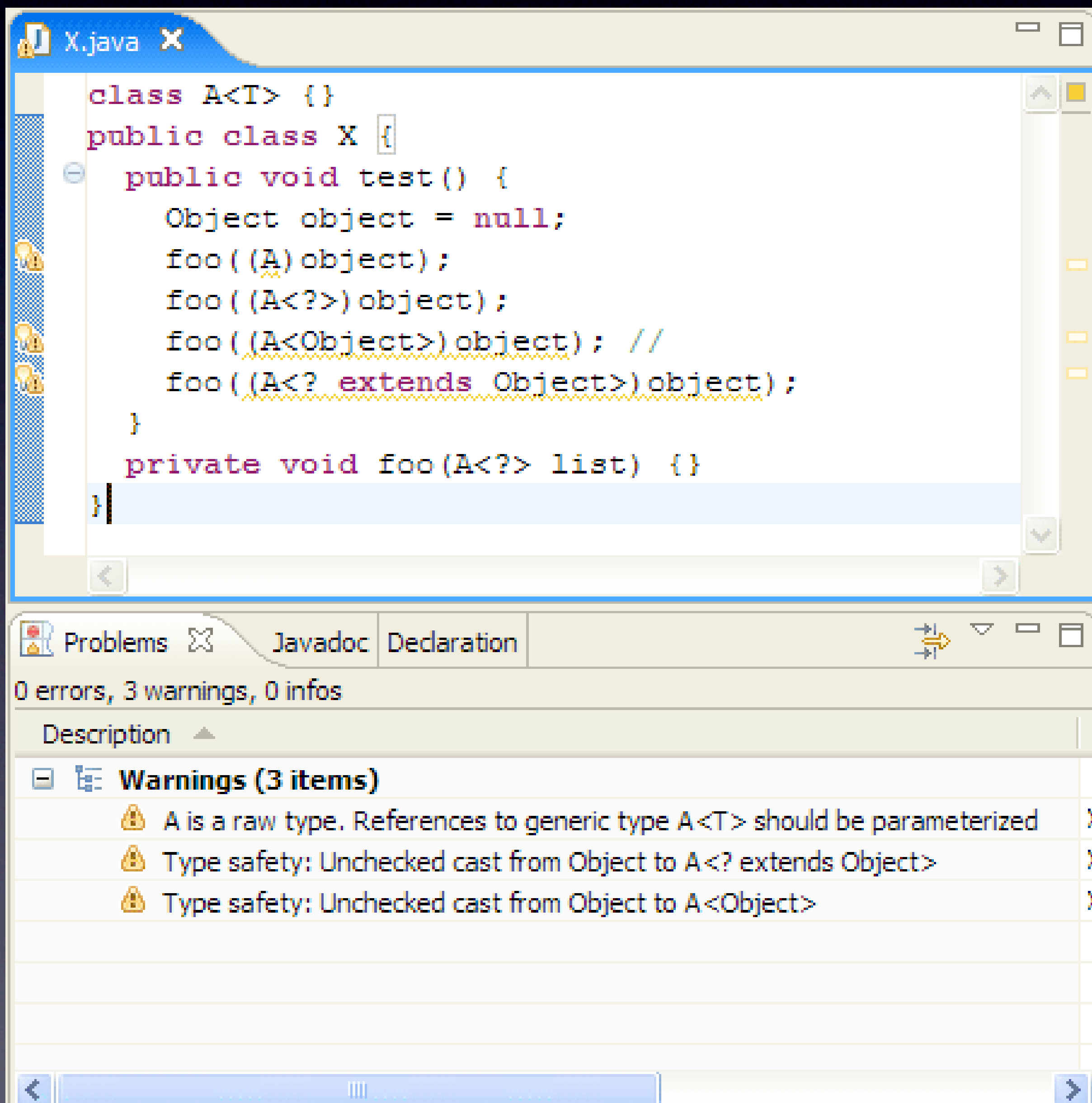
dependant

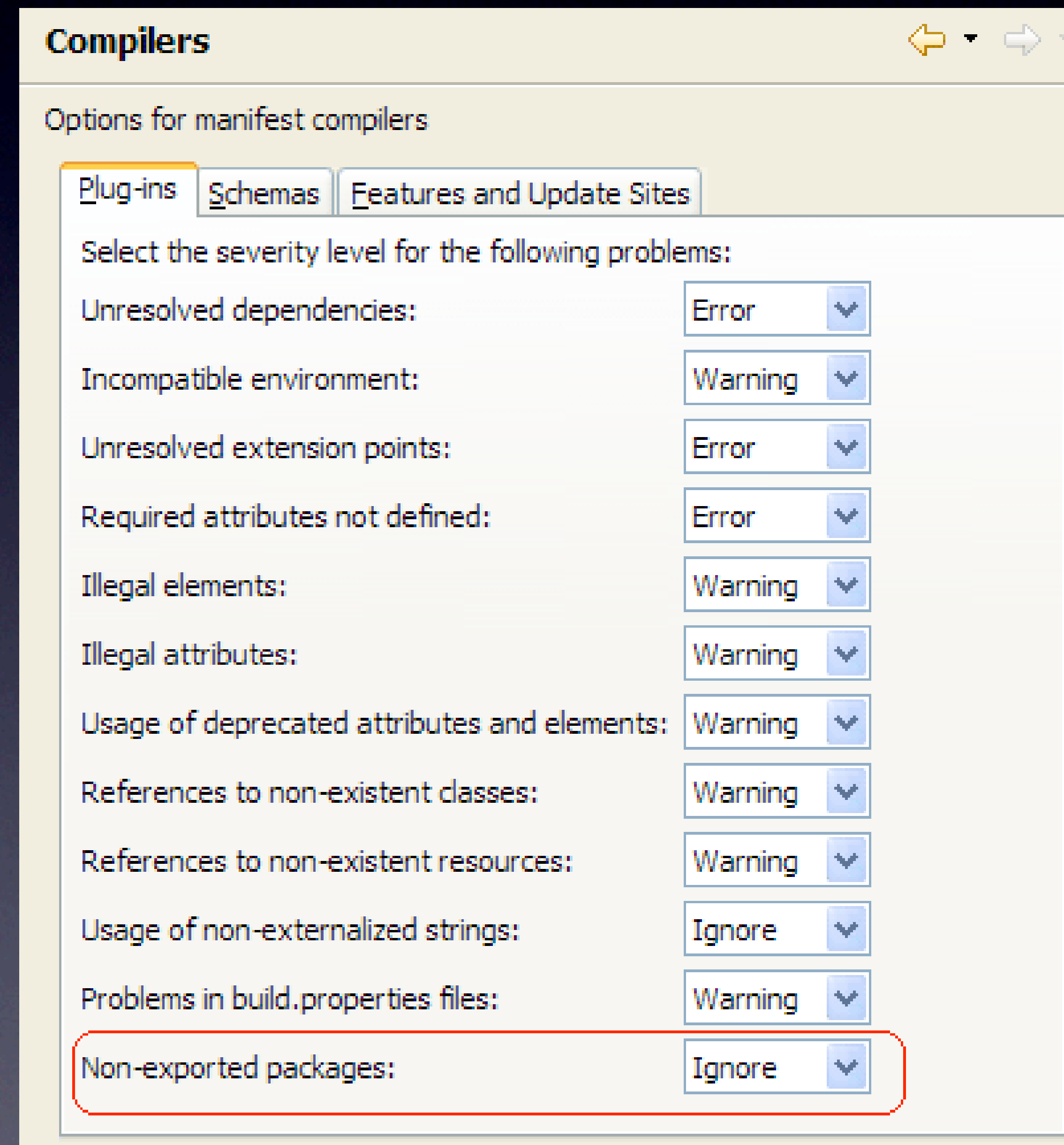
Aggregate	Hard Bugs Yes	Hard Bugs No	Totals
Yes	372	573	945
No	179	931	1110
Totals	551	1504	2055

$T = 140.48$, p-value $= 0.00$

dependant

Eclipse


X.java
class A<T> {}
public class X {
public void test() {
Object object = null;
foo((A)object);
foo((A<?>)object);
foo((A<Object>)object); //
foo((A<? extends Object>)object);
}
private void foo(A<?> list) {}
}
Problems
Javadoc
Declaration
0 errors, 3 warnings, 0 infos
Description
Warnings (3 items)
A is a raw type. References to generic type A<T> should be parameterized
Type safety: Unchecked cast from Object to A<? extends Object>
Type safety: Unchecked cast from Object to A<Object>


Compilers
Options for manifest compilers
Plug-ins
Schemas
Features and Update Sites
Select the severity level for the following problems:
Unresolved dependencies: Error
Incompatible environment: Warning
Unresolved extension points: Error
Required attributes not defined: Error
Illegal elements: Warning
Illegal attributes: Warning
Usage of deprecated attributes and elements: Warning
References to non-existent classes: Warning
References to non-existent resources: Warning
Usage of non-externalized strings: Ignore
Problems in build.properties files: Warning
Non-exported packages: Ignore

FindBugs

Bill Pugh

FindBugs: Bug patterns

FindBugs recognizes 284 different bug patterns

http://findbugs.sourceforge.net/bugDescriptions.html

AM: Creates an empty jar file entry; AM: Creates an empty zip file entry; BC: Equals method should not assume anything about the type of its argument; BC: Random object created and used only once; CN: Class implements Cloneable but does not define or use clone method; CN: clone method does not call super.clone(); Co: Abstract class defines covariant compareTo() method; Co: Covariant compareTo() method defined; DE: Method might drop exception; DE: Method might ignore exception; DP: Classloaders should only be created inside doPrivileged block; DP: Method invoked that should be only be invoked inside a doPrivileged block; Dm: Method invokes System.exit(...); Dm: Method invokes dangerous method runFinalizersOnExit; ES: Comparison of String parameter using == or !=; ES: Comparison of String objects using == or !=; Eq: Abstract class defines covariant equals() method; Eq: Class defines compareTo(...) and uses Object.equals(); Eq: Covariant equals() method defined; Eq: Covariant equals() method defined, Object.equals(Object) inherited; FI: Empty finalizer should be deleted; FI: Explicit invocation of finalizer; FI: Finalizer nulls fields; FI: Finalizer only nulls fields; FI: Finalizer does not call superclass finalizer; FI: Finalizer nullifies superclass finalizer; FI: Finalizer does nothing but call superclass finalizer; HE: Class defines equals() but not hashCode(); HE: Class defines equals() and uses Object.hashCode(); HE: Class defines hashCode() but not equals(); HE: Class defines hashCode() and uses Object.equals(); HE: Class inherits equals() and uses Object.hashCode(); IC: Superclass uses subclass during initialization; IMSE: Dubious catching of IllegalMonitorStateException; ISC: Needless instantiation of class that only supplies static methods; It: Iterator next() method can't throw NoSuchElement exception; J2EE: Store of non serializable object into HttpSession; NP: Clone method may return null; NP: equals() method does not check for null argument; NP: toString method may return null; NS: Questionable use of non-short-circuit logic; Nm: Class names should start with an upper case letter; Nm: Class is not derived from an Exception, even though it is named as such; Nm: Confusing method names; Nm: Field names should start with an lower case letter; Nm: Use of identifier that is a keyword in later versions of Java; Nm: Use of identifier that is a keyword in later versions of Java; Nm: Method names should start with an lower case letter; Nm: Very confusing method names (but intentional); ODR: Method may fail to close database resource; ODR: Method may fail to close database resource on exception; OS: Method may fail to close stream; OS: Method may fail to close stream on exception; RR: Method ignores results of InputStream.read(); RR: Method ignores results of InputStream.skip(); SI: Static initializer creates instance before all static final fields assigned; SQL: Nonconstant string passed to execute method on an SQL statement; SQL: A prepared statement is generated from a nonconstant String; SW: Certain swing methods needs to be invoked in Swing thread; Se: Non-transient non-serializable instance field in serializable class; Se: Non-serializable class has a serializable inner class; Se: Non-serializable value stored into instance field of a serializable class; Se: Comparator doesn't implement Serializable; Se: Serializable inner class; Se: Method must be private in order for serialization to work; Se: serialVersionUID isn't final; Se: serialVersionUID isn't long; Se: serialVersionUID isn't static; Se: Class is Serializable but its superclass doesn't define a void constructor; Se: Class is Externalizabl … tion.; SnVI: Class is Serializable, but doesn't define serialVersionUID; UI: Usage of GetResource may be unsa … masks; BIT: Bitwise OR of signed byte value; BOA: Class overrides a method implemented in super class Adapter … vokes next; DMI: Invocation of toString on an array; DMI: Double.longBitsToDouble invoked on an int; Dm: Can … hich is equivalent to ==; EC: Call to equals() with null argument; EC: Call to equals() comparing unrelated … num; FE: Doomed test for equality to NaN; GC: No relationship between generic parameter and method ar … uble and then passed to Math.ceil; ICAST: int value cast to float and then passed to Math.round; IJU: JUnit assert … uper.setUp(); IJU: TestCase implements a non-static suite method; IJU: TestCase implements tearDown but doesn' … mainder; INT: Bad comparison of nonnegative value with negative constant; INT: Bad comparison of signed byte; … field that masks a superclass field; MF: Method defines a variable that obscures a field; NP: Null pointer deref … P: Value is null and guaranteed to be dereferenced on exception path; NP: Method call passes null to a nonn … dereference; NP: Possible null pointer dereference in method on exception path; NP: Method call passes null … nconditionally dereferenced parameter; NP: Store of null value into field annotated NonNull; NP: Read of unwritten field; NS: Potentially dangerous use of non-short-circuit logic; Nm: Class defines equal(); should it be equals()?; Nm: Class defines hashcode(); should it be hashCode()?; Nm: Class defines tostring(); should it be toString()?; Nm: Apparent method/constructor confusion; Nm: Very confusing method names; QBA: Method assigns boolean literal in boolean expression; RC: Suspicious reference comparison; RCN: Nullcheck of value previously dereferenced; RE: Invalid syntax for regular expression; RE: File.separator used for regular expression; RE: "." used for regular expression; RV: Random value from 0 to 1 is coerced to the integer 0; RV: Bad attempt to compute absolute value of signed 32-bit hashcode; RV: Bad attempt to compute absolute value of signed 32-bit random integer; RV: Method discards result of readLine after checking if it is nonnull; RV: Method ignores return value; SA: Double assignment of field; SA: Self assignment of field; SA: Self comparison of field with itself; SA: Nonsensical self computation involving a field (e.g., x & x); SA: Double assignment of local variable; SA: Self comparison o … ck done using instanceof operator; SQL: Method attempts to access a prepared statement parameter with index 0; … d invoked on thread instance; UCF: Useless control flow to next line; UMAC: Uncallable method defined in anon … iable number of object arguments; Dm: Consider using Locale parameterized version of invoked method; EI: Ma … nalizer should be protected, not public; MS: May expose internal static state by storing a mutable object into a s … ould be both final and package protected; MS: Field is a mutable array; MS: Field is a mutable Hashtable; MS: Field … k of field; Dm: Monitor wait() called on Condition; Dm: A thread was created using the default empty run metho … rrent Lock; LI: Incorrect lazy initialization of static field; ML: Method synchronizes on an updated field; MWN: M … s readObject() method is synchronized; Ru: Invokes run on a thread (did you mean to start it instead?); SC: Con … teFormat; SWL: Method calls Thread.sleep() with a lock held; TLW: Wait with two locks held; UG: Unsynchroniz … wait; VO: A volatile reference to an array doesn't treat the array elements as volatile; WS: Class's writeObject() … mitive value is boxed then unboxed to perform primative coercion; Bx: Method allocates a boxed primitive just to … se static valueOf instead; Dm: The equals and hashCode methods of URL are blocking; Dm: Maps and sets of URLs can be performance hogs; Dm: Method invokes inefficient Boolean constructor; use Boolean.valueOf(...) instead; Dm: Explicit garbage collection; extremely dubious except in benchmarking code; Dm: Method allocates an object, only to get the class object; Dm: Use the nextInt method of Random rather than nextDouble to generate a random integer; Dm: Method invokes inefficient new String(String) constructor; Dm: Method invokes inefficient String.equals(""); use String.length() == 0 instead; Dm: Method invokes toString() method on a String; Dm: Method invokes inefficient new String() constructor; HSC: Huge string constants is duplicated across multiple class files; ITA: Method uses toArray() with zero-length array argument; SBSC: Method concatenates strings using + in a loop; SIC: Should be a static inner class; SIC: Could be refactored into a named static inner class; SIC: Could be refactored into a static inner class; SS: Unread field: should this field be static?; UM: Method calls static Math class method on a constant value; UPM: Private method is never called; UrF: Unread field; UuF: Unused field; WMI: Inefficient use of keySet iterator instead of entrySet iterator; BC: Questionable cast to abstract collection; BC: Questionable cast to concrete collection; BC: Unchecked/unconfirmed cast; BC: instanceof will always return true; CI: Class is final but declares protected field; DB: Method uses the same code for two branches; DB: Method uses the same code for two switch clauses; DLS: Dead store to local variable; DLS: Dead store of null to local variable; DMI: Code contains a hard coded reference to an absolute pathname; DMI: Non serializable object written to ObjectOutput; DMI: Invocation of substring(0), which returns the original value; Dm: Thread passed where Runnable expected; FE: Test for floating point equality; IA: Ambiguous invocation of either an inherited or outer method; IC: Initialization circularity; ICAST: int division result cast to double or float; ICAST: Result of integer multiplication cast to long; ICAST: Unsigned right shift cast to short/byte; IM: Computation of average could overflow; IM: Check for oddness that won't work for negative numbers; INT: Vacuous comparison of integer value; MTIA: Class extends Servlet class and uses instance variables; MTIA: Class extends Struts Action class and uses instance variables; NP: Immediate dereference of the result of readLine(); NP: Load of known null value; NP: Possible null pointer dereference due to return value of called method; PZLA: Consider returning a zero length array rather than null; QF: Complicated, subtle or wrong increment in for-loop; RCN: Redundant comparison of non-null value to null; RCN: Redundant comparison of two null values; RCN: Redundant nullcheck of value known to be non-null; RCN: Redundant nullcheck of value known to be null; REC: Exception is caught when Exception is not thrown; RI: Class implements same interface as superclass; RV: Method checks to see if result of String.indexOf is positive; RV: Remainder of hashCode could be negative; RV: Remainder of 32-bit signed random integer; SA: Self assignment of local variable; SF: Switch statement found where one case falls through to the next case; ST: Write to static field from instance method; Se: Transient field of class that isn't Serializable.; UCF: Useless control flow; UwF: Field not initialized in constructor; XFB: Method directly allocates a specific implementation of xml interfaces

FindBugs: Infinite Loops

- Students are good bug generators:
```
public WebSpider() {
    WebSpider w = new WebSpider();
}
```
- Five infinite loops in JDK1.6.0-b13,
27 across all versions of JDK,
31 in Google's Java code

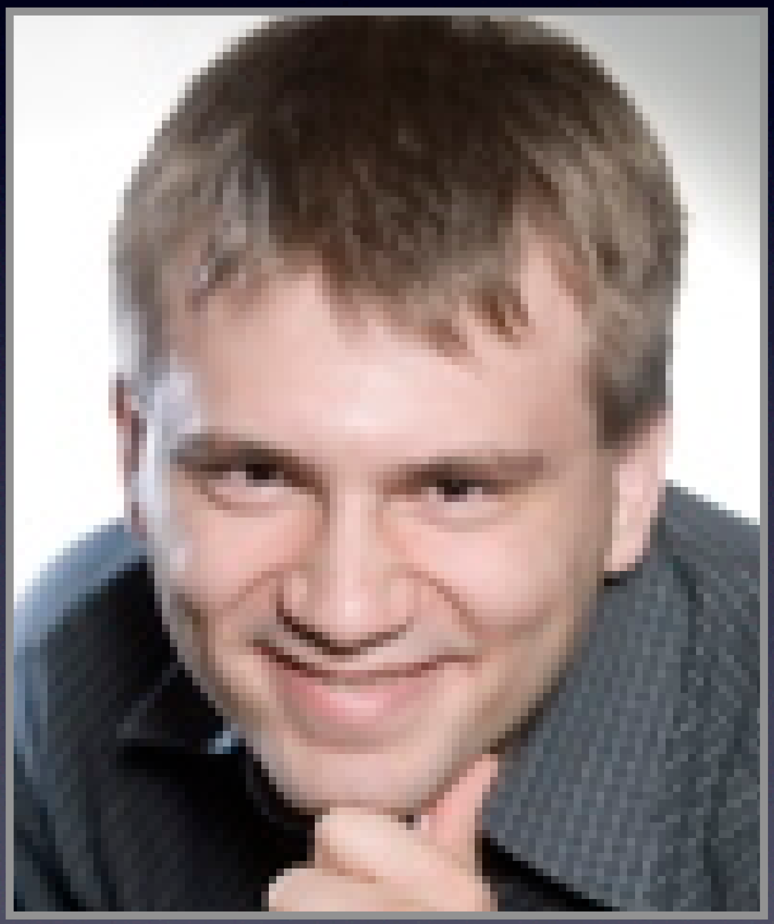
More: http://findbugs.cs.umd.edu/talks/JavaOne2007-TS2007.pdf

Use of history

- Track warnings across releases
  Jaime Spacco, David Hovemeyer, William Pugh: Tracking defect warnings across versions. MSR 2006: 133-136
- Rank warnings with historic data
  Chadd C. Williams, Jeffrey K. Hollingsworth: Automatic Mining of Source Code Repositories to Improve Bug Finding Techniques. IEEE Trans. Software Eng. 31(6): 466-480 (2005)

  Sunghun Kim, Michael D. Ernst: "Which Warnings Should I Fix First?" ESEC/FSE 2007, to appear

Meet & Greet



Andrzej
Wasylkowski

Slides will be available
on the lecture web-page.

Statistical bug isolation

Ben Liblit

PLDI 2005 Slides at http://pages.cs.wisc.edu/~liblit/pldi-2005/

References

- Yichen Xie, Dawson R. Engler: Using redundancies to find errors. SIGSOFT FSE 2002: 51-60
- Bill Pugh: FindBugs™ - Find Bugs in Java Programs. http://findbugs.sourceforge.net/
- Andrzej Wasylkowski, Andreas Zeller: Detecting Object Usage Anomalies. ESEC/FSE 2007, to appear
- Ben Liblit, Mayur Naik, Alice X. Zheng, Alexander Aiken, Michael I. Jordan: Scalable statistical bug isolation. PLDI 2005: 15-26