Introducing virtual field and rename dispatching based on type view stack to fix Eiffel's field renaming loophole

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Among all the object-oriented programming (OOP) languages that support multiple inheritance (MI), Eiffel is unique for its distinctive renaming mechanism, which is designed to address name clashes of each class member individually in the derived classes. However, we discovered a loophole in Eiffel's field renaming mechanism when applied to the diamond problem of MI, and confirmed it by showing divergent and problematic outputs for the same example code in three major different Eiffel compilers. To fix the loophole we propose to abandon the renaming's reference identity semantics; we introduce a concept called *virtual field*, and propose two methods: the first method is manual fix with help from enhanced programming rules, e.g. direct virtual field access is only allowed in accessor methods (among other rules); and the second method is automatic, we introduce rename dispatching based on the object's runtime types' *view stack*, and provide formalized new programming rules. Hence providing an improved solution to multiple inheritance.

All the source code of this paper can be found in the supplementary material: eiffel_rename.tgz.

CCS Concepts: • **Software and its engineering** → **General programming languages**.

Additional Key Words and Phrases: virtual field, rename dispatching, view stack, (unplanned) multiple inheritance (MI), diamond problem, Eiffel language, name clash resolution

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1 MOTIVATION: THE DIAMOND PROBLEM

The most well known problem in multiple inheritance (MI) is the diamond problem [Snyder 1987] [Knudsen 1988] [Sakkinen 1989], for example on the popular website (for everyday working programmers) wikipedia [1] it is described as:

> The "diamond problem" is an ambiguity that arises when two classes B and C inherit from A, and class D inherits from both B and C. If there is a method in A that B and C have overridden, and D does not override it, then which version of the method does D inherit: that of B, or that of C?

Actually in the real world engineering practice, for any *method*'s ambiguity e.g. foo(), it is relatively easy to resolve *by the programmers*:

- just *override* it in D.foo(), or
- explicitly use fully quantified method names, e.g. A.foo(), B.foo(), or C.foo().

The more difficult problem is how to handle the *data members (i.e. fields)* inherited from A: shall D have one joined copy or two separate copies of A's fields (or mixed fields with some are joined, and others separated)? For example, in C++ [Stroustrup 1991], the former is called virtual inheritance, and the latter is default (regular) inheritance. But C++ does

[1] https://en.wikipedia.org/wiki/Multiple_inheritance#The_diamond_problem

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not completely solve this problem, for example let's build an object model for PERSON, STUDENT, FACULTY, and RESEARCH_ASSISTANT in a university:

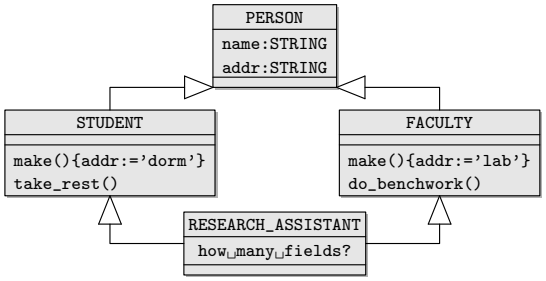

Fig. 1. the diamond problem in multiple inheritance

The intended semantics is that a RESEARCH_ASSISTANT should have only 1 name field, but 2 address fields: one "dorm" as STUDENT to take_rest(), and one "lab" as FACULTY to do_benchwork(); so in total 3 fields. However, in C++'s plain MI we can either do:

(1) virtual inheritance: RESEARCH_ASSISTANT will have 1 `name`, and 1 `addr`; or
(2) default inheritance: RESEARCH_ASSISTANT will have 2 `name`s, and 2 `addr`s.

Hence with C++'s plain MI mechanism, RESEARCH_ASSISTANT will have either one whole copy (2 fields in total), or two whole copies (4 fields in total) of PERSON's all data members. This leaves something better to be desired.

Among all the OOP languages that support MI, Eiffel is unique in that it provides a renaming mechanism designed to resolve name clashes of each class member *individually* in the derived classes. Let's check how Eiffel models this example in the next Section 2, then we will examine the semantics of Eiffel's renaming mechanism in Section 2.2, and show the loophole we discovered in 2.3. In Section 3 we will fix the loophole with a manual approach, by introducing the concept of virtual fields and proposing some enhanced programming rules. In Section 4 we will introduce rename dispatching based on view stack to fix the loophole automatically with an experimental compiler, and describe our implementation in Section 5. In Section 6 we will discuss Eiffel's renamed methods, and compare virtual method dispatch and rename dispatching. In Section 7 we will discuss some related works. Finally, we summarize our work in Section 8.

2 EIFFEL'S RENAMING MECHANISM[2]

To simulate *unplanned*[3] MI, let's assume each class is developed by different software vendors independently – hence uncoordinated, but in the topological order of inheritance directed acyclic graph (*DAG* for MI; while for single inheritance, it's inheritance *tree*), starting from the top base classes. And if class B inherits from A, we say B('s level) is *below* A.

The first vendor developed class PERSON, each person has a name and an address:

Listing 1. person.e (Eiffel)

```
1 class PERSON
```

[2]Note: all the code listings in this section are compilable and executable, so it's a bit verbose.
[3]By unplanned MI, we mean when a programmer works on class C, s/he cannot make any changes to any of C's superclasses. So the programming language has to provide good feature adaptation mechanisms to allow the programmer of class C to achieve the intended semantics.

```
inherit ANY -- redefine default_create end  -- needed by ISE and GOBO compiler; but not by SmartEiffel

create {ANY}
   default_create

feature {ANY}
   name: STRING
   addr: STRING

   get_addr():STRING  is do Result := addr end  -- accessor method, to read
   set_addr(a:STRING) is do addr   := a    end  -- accessor method, to write

   default_create is  -- the constructor
     do
       name := "name"
       addr := "addr"
     end
end
```

The second vendor developed class STUDENT: added set/get_student_addr() accessors, and take_rest() method, since PERSON has the `addr` field already, the second vendor just uses it instead of adding another field:

Listing 2. student.e (Eiffel)

```
class STUDENT
inherit PERSON

create {ANY}
   default_create


feature {ANY}
   get_student_addr():STRING  is do Result := get_addr() end  -- assign dorm semantics to addr
   set_student_addr(a:STRING) is do set_addr(a) end

   take_rest() is
     do
       io.put_string(name + " take_rest in the: " + get_student_addr() + "%N");
     end
end
```

At the *same time* as the second vendor, the third vendor developed class FACULTY: added set/get_faculty_addr() accessors, and do_benchwork() method, in the same way to reuse the inherited field `PERSON.addr` instead of adding another field:

Listing 3. faculty.e

```
class FACULTY
inherit PERSON

create {ANY}
   default_create


feature {ANY}
   get_faculty_addr():STRING  is do Result := get_addr() end  -- assign lab semantics to addr
   set_faculty_addr(a:STRING) is do set_addr(a) end

   do_benchwork() is
     do
       io.put_string(name + " do_benchwork in the: " + get_faculty_addr() + "%N");
     end
end
```

Definition 1 (semantic branching site of field)**.** At this point, we can see the two different inheritance branches of PERSON have assigned different semantics to the same inherited field `addr`, we call class PERSON as the *semantic branching site of field* `addr`.

By contrast, in the whole inheritance DAG of this example, there is no semantic branching site of field `name`.

2.1 Eiffel MI: individual feature renaming

With Eiffel's renaming mechanism to treat each inherited feature (field or method) individually from the super-classes, we implement RESEARCH_ASSISTANT as listing 4.

Listing 4. research_assistant.e

```
1  class RESEARCH_ASSISTANT
2  inherit
3          STUDENT rename addr as student_addr end  -- field student_addr inherit the dorm semantics
4          FACULTY rename addr as faculty_addr end  -- field faculty_addr inherit the lab  semantics
5          -- then select, NOTE: not needed by SmartEiffel, but needed by GOBO and ISE compiler
6          PERSON  select addr end
7
8  create {ANY}
9     make
10
11 feature {ANY}
12    print_ra() is  -- print out all 3 addresses
13       do
14         io.put_string(name +" has 3 addresses: <"+ addr +", "+ student_addr +", "+ faculty_addr + ">%N")
15       end
16
17    make is  -- the constructor
18       do
19         name := "ResAssis"
20         addr := "home"          -- the home semantics
21         student_addr := "dorm"  -- the dorm semantics
22         faculty_addr := "lab"   -- the lab  semantics
23       end
24 end
```

Definition 2 (renaming site of a field)**.** If a class A has renamed any of its super-class(es)' field, we call A the *renaming site* of the field.

For example, RESEARCH_ASSISTANT is the renaming site for both STUDENT.addr and FACULTY.addr.

Please note, we have made RESEARCH_ASSISTANT inherited from PERSON 3 times: 2 times indirectly via STUDENT and FACULTY, and 1 time directly from PERSON. Thus, RESEARCH_ASSISTANT has 1 `name` field (inherited fields with the same name are joined in Eiffel by default), and 3 address fields. The extra inheritance from PERSON is to make the inheritance from STUDENT and FACULTY symmetric, which helps easy exposition of the next Section 4 when we discuss view stacks.[4]

[4]Note: strictly speaking the `select addr end` clause on line 6 is not needed, because after the two renamings on line 3 and 4, there is no more name clash on RESEARCH_ASSISTANT's field `addr`, hence no ambiguity. However some Eiffel compilers (e.g. GOBO and ISE) enforce the presence of this `select` clause which we think is wrong, while others (e.g. SmartEiffel) do not.

The Eiffel `select` clause allows the programmer to *explicitly* resolve name clash on each inherited feature *individually*, which we believe is a better solution than imposing the *same* method resolution order (MRO) [Barrett et al. 1996] to *all* features as in many other OOP languages, e.g. Python [van Rossum 2010]: the base classes' order in the inheritance clause should *not* matter.

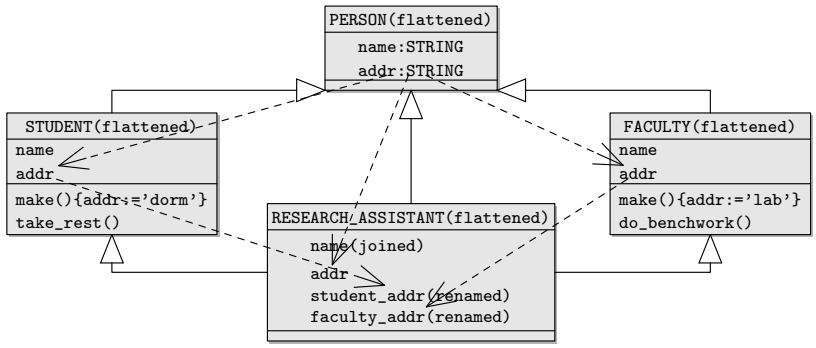

Fig. 2. flattened fields view, and feature renaming DAG of field 'addr' (dashed arrows)

The above diagram shows the field flattened view of the classes implemented in Eiffel; in particular, the dashed arrows show how the field `addr` is inherited (and renamed) in the class hierarchy, we call it *feature renaming DAG* of `addr`.

2.2 Exam the semantics of the renamed fields

We want to study how the renamed field behaves in this diamond inheritance. In ECMA-367 [ECMA 2006][5] Section 8.16.2, it says:

> Let D be a class and $B_1, B_n (n \geq 2)$ be parents of D based on classes having a common ancestor A. ... Any two of these features inherited under a different name yield two features of D.

Which means the purpose of the renaming mechanism is to have *separate* copies for the name-clashed field. In Section 8.6.16, we only find a very brief description of its semantics:

> Renaming principle: Renaming does not affect the semantics of an inherited feature.

so we have to look further elsewhere: from [Meyer 1997] 15.2 page 544-545, we found some concrete examples[6]

```
class SANTA_BARBARA inherit
  LONDON   rename foo as fog end
  NEW_YORK rename foo as zoo end
feature
  ...
end
```

`l: LONDON; n: NEW_YORK; s: SANTA_BARBARA`
Then l.foo and s.fog are both valid; after a polymorphic assignment l := s they would have the same effect, since the feature names represent the same feature. Similarly n.foo and s.zoo are both valid, and after n := s they would have the same effect.
None of the following, however, is valid:

- l.zoo, l.fog, n.zoo, n.fog since neither LONDON nor NEW_YORK has a feature called fog or zoo.

[5]It serves as Eiffel language standard specification.
[6]NOTE: in this quoted example `foo, fog & zoo` are methods, but according to Eiffel's Principle of Uniform Access [ECMA 2006] page 8, methods and fields can be used interchangeably. We will discuss them as fields.

- s.foo since as a result of the renaming SANTA_BARBARA has no feature called foo.[7]

From these descriptions, we can conclude in Eiffel renaming is a *reference identity* relation between the original field and the new renamed field, let's use = to denote this relationship[8].

However, we think there are two problems here: suppose both `LONDON` and `NEW_YORK` actually inherited `foo` from their common super-class `CITY` (i.e. form a diamond inheritance relationship), and `c: CITY`, after `c := s`

2.2.1 No feature separation achieved. Because

- `c.foo = l.foo = s.fog`, and
- `c.foo = n.foo = s.zoo`

then it follows: `s.fog = s.zoo`, which means there is *no feature separation achieved* at all! We think this simple reference identity semantics of field renaming is a loophole in Eiffel, as demonstrated in this diamond problem.

2.2.2 No needed feature renaming dispatch found. Another problem is: suppose there is a method `m()` in `CITY` that accesses feature `foo` in `CITY`, then when `m()` is invoked on a `SANTA_BARBARA` object, i.e `c.m()`, which `s.fog` or `s.zoo` will be accessed? We have not find any discussion of this needed feature renaming dispatch (i.e. from `c.foo` to either `s.fog` or `s.zoo`) in Eiffel literature.

To confirm our suspicion, we will verify it with the actual Eiffel compilers.

2.3 Verify the loophole with real Eiffel compilers

Let's create a RESEARCH_ASSISTANT object, and call the method do_benchwork() and take_rest() on it, and check the outputs:

Listing 5. app.e

```
-- to build with SmartEiffel: compile  app.e -o app
class APP -- inherit INTERNAL

create {ANY}
   make

feature {ANY}
   ra: RESEARCH_ASSISTANT
   p:  PERSON
   s:  STUDENT
   f:  FACULTY

   -- problematic implementation: direct field access
   print_student_addr_direct_field(u: STUDENT) is
      do io.put_string(u.name + " as STUDENT.addr: " + u.addr + "%N") end
   print_faculty_addr_direct_field(u: FACULTY) is
      do io.put_string(u.name + " as FACULTY.addr: " + u.addr + "%N") end

   -- correct implementation: use semantic assigning accessor
   print_student_addr_via_accessor(u: STUDENT) is
      do io.put_string(u.name + " as STUDENT.addr: " + u.get_student_addr() + "%N") end
   print_faculty_addr_via_accessor(u: FACULTY) is
      do io.put_string(u.name + " as FACULTY.addr: " + u.get_faculty_addr() + "%N") end

   make is
      do
         create  p.default_create
         create  s.default_create
         create  f.default_create
         create ra.make
```

[7]This example actually also demonstrates why the `select addr end` clause in class RESEARCH_ASSISTANT is not necessary: after two renamings, there is no more name clash on `addr`.
[8]In Eiffel syntax, = is used to test reference identity.

```
        ra.print_ra()
        -- io.put_string("PERSON  size: " +physical_size(p ).out+ "%N")
        -- io.put_string("STUDENT size: " +physical_size(s ).out+ "%N")
        -- io.put_string("FACULTY size: " +physical_size(f ).out+ "%N")
        -- io.put_string("RESEARCH_ASSISTANT size: " +physical_size(ra).out+ "%N")

        ra.do_benchwork()  -- which addr field will this call access?
        ra.take_rest()     -- which addr field will this call access?

        io.put_string("-- print_student|faculty_addr_direct_field%N")
        print_student_addr_direct_field(ra)
        print_faculty_addr_direct_field(ra)

        io.put_string("-- print_student|faculty_addr_via_accessor%N")
        print_student_addr_via_accessor(ra)
        print_faculty_addr_via_accessor(ra)

        io.put_string("-- check reference identity%N")
        if                  ra.addr  = ra.faculty_addr
        then io.put_string("ra.addr  = ra.faculty_addr%N")
        else io.put_string("ra.addr != ra.faculty_addr%N") end

        if                  ra.addr  = ra.student_addr
        then io.put_string("ra.addr  = ra.student_addr%N")
        else io.put_string("ra.addr != ra.student_addr%N") end

        if                  ra.student_addr  = ra.faculty_addr
        then io.put_string("ra.student_addr  = ra.faculty_addr%N")
        else io.put_string("ra.student_addr != ra.faculty_addr%N") end

        io.put_string("-- test: suppose ra moved both lab2 and dorm2%N")
        ra.set_faculty_addr("lab2")
        ra.print_ra()
        ra.set_student_addr("dorm2")
        ra.print_ra()
      end
end
```

We have tested all the three major Eiffel compilers that we can find on the internet:

(1) the latest ISE EiffelStudio[9] 23.09.10.7341 (released in 2023)
(2) the open source Gobo Eiffel compiler gec version 22.01.09.4[10] (released in 2022)
(3) the open source GNU SmartEiffel version 1.1[11] (released in 2003)

All three compilers generate problematic outputs:

Listing 6. ISE EiffelStudio output: most of the lines are wrong

```
ResAssis has 3 addresses: <home, home, home>  -- all 3 addr is "home"! no feature separation at all!
PERSON  size: 32
STUDENT size: 32
FACULTY size: 32
RESEARCH_ASSISTANT size: 48
ResAssis do_benchwork in the: home
ResAssis take_rest in the: home
-- print_student|faculty_addr_direct_field
ResAssis as STUDENT.addr: home
ResAssis as FACULTY.addr: home
-- print_student|faculty_addr_via_accessor
ResAssis as STUDENT.addr: home
ResAssis as FACULTY.addr: home
-- check reference identity
ra.addr  = ra.faculty_addr
ra.addr  = ra.student_addr
ra.student_addr  = ra.faculty_addr
-- test: suppose ra moved both lab2 and dorm2
ResAssis has 3 addresses: <lab2, lab2, lab2>
ResAssis has 3 addresses: <dorm2, dorm2, dorm2>
```

[9] https://www.eiffel.com/company/leadership/ the company with Eiffel language designer Dr. Bertrand Meyer as CEO and Chief Architect, Founder. Actually we tested both version 22.12.10.6463 (released in 2022) and 23.09.10.7341.

[10] https://github.com/gobo-eiffel/gobo

[11] in later years, SmartEiffel was divergent from the ECMA Eiffel standard, so we choose to test version 1.1 (the last version of 1.x).

From ISE output, we can see our suspicion is confirmed: it demonstrates a few problems:

(1) line 2 – 5 show the object size in bytes, we can see indeed `RESEARCH_ASSISTANT` is bigger than both `STUDENT` and `FACULTY`, which means it has more data fields; while line 15 – 17 (check reference identity) [12], it demonstrates the renaming language construct does not help to achieve feature separation at all, this is a language loophole.
(2) Moreover, the 1st line of the ISE compiler output is three "home" strings! if we check the constructor `RESEARCH_ASSISTANT.make()` in listing 4, we can see the last assignment statement is `faculty_addr := "lab"`, even with reference identity semantics this output is wrong, so we think this is an ISE compiler bug (also compare it with the line 19 – 20).
(3) line 6 & 7, do_benchwork() and take_rest() all output "home", it failed to fulfill the programmer's intention.
(4) again, the last two lines 19 – 20, although it achieved the renaming's reference identity semantics, it does not achieve feature separation.

Listing 7. GOBO output

```
ResAssis has 3 addresses: <home, dorm, lab>
PERSON  size: 24
STUDENT size: 24
FACULTY size: 24
RESEARCH_ASSISTANT size: 40
ResAssis do_benchwork in the: home
ResAssis take_rest in the: home
-- print_student|faculty_addr_direct_field
ResAssis as STUDENT.addr: home  -- wrong read
ResAssis as FACULTY.addr: home  -- wrong read
-- print_student|faculty_addr_via_accessor
ResAssis as STUDENT.addr: home
ResAssis as FACULTY.addr: home
-- check reference identity
ra.addr != ra.faculty_addr
ra.addr != ra.student_addr
ra.student_addr != ra.faculty_addr
-- test: suppose ra moved both lab2 and dorm2
ResAssis has 3 addresses: <lab2, dorm, lab>   -- wrong
ResAssis has 3 addresses: <dorm2, dorm, lab>  -- wrong
```

Listing 8. SmartEiffel output

```
ResAssis has 3 addresses: <home, dorm, lab>
PERSON  size: 12
STUDENT size: 12
FACULTY size: 12
RESEARCH_ASSISTANT size: 20
ResAssis do_benchwork in the: home
ResAssis take_rest in the: home
-- print_student|faculty_addr_direct_field
ResAssis as STUDENT.addr: home
ResAssis as FACULTY.addr: home
-- print_student|faculty_addr_via_accessor
ResAssis as STUDENT.addr: home
ResAssis as FACULTY.addr: home
-- check reference identity
ra.addr != ra.faculty_addr
ra.addr != ra.student_addr
ra.student_addr != ra.faculty_addr
-- test: suppose ra moved both lab2 and dorm2
ResAssis has 3 addresses: <lab2, dorm, lab>
ResAssis has 3 addresses: <dorm2, dorm, lab>
```

From line 1 & 14 – 17, we can see GOBO indeed separate the 3 address fields (N.B. this output shows it does *not* implement the reference identity semantics, so we think it is not a standard compliant compiler), but it failed to achieve the programmer's intended semantics:

(1) line 6 & 7, do_benchwork() and take_rest() all output "home", same problem as ISE
(2) line 19 – 20, for assignment:
    - `ra.set_faculty_addr("lab2")`, and
    - `ra.set_student_addr("dorm2")`

    it wrongly changed the value of `RESEARCH_ASSISTANT.addr`, while the very reason the programmer introduced renaming is want to
    - modify `RESEARCH_ASSISTANT.student_addr` on the `ra` object, and
    - modify `RESEARCH_ASSISTANT.faculty_addr` on the `ra` object

SmartEiffel's output is mostly the same as GOBO output (except the object size which is compiler dependent), and both compilers do *not* implement the reference identity semantics.

[12] In Eiffel, "=" means reference identity testing

In particular, we can see for all the three compilers: the do_benchwork() method calls all print out the *problematic* address "home", while the programmer's intention is "lab"; and take_rest() print out "home" instead of "dorm".

Please also note: currently FACULTY.do_benchwork() calls FACULTY.get_faculty_addr(), and then PERSON.get_addr() to access the field `addr`; even if we change FACULTY.do_benchwork() or FACULTY.get_faculty_addr() to access the field `addr` directly, the output is still the same, which we have tested; and interested readers are welcome to verify it.

We choose to define these three pairs of seemingly redundant accessor methods:

- `PERSON.set/get_addr()`
- `STUDENT.set/get_student_addr()`
- `FACULTY.set/get_faculty_addr()`

for the purpose of easy exposition of the next Section 3. In the next two sections, we will fix the loophole we have found with two different methods.

3 VIRTUAL FIELD, AND ITS ENHANCED ACCESSOR RULES

The first method is we will add enhanced accessor rules of the renamed fields to the compiler, and help the programmer to access these fields with disciplines.

3.1 Memory layout

Let us examine the flattened view of the fields of each class. Since most Eiffel compilers generate C code as target, let's use C to make our discussion more concrete.

The intended memory layout of each flattened class with multiple inheritance and renaming is shown on the right:

```
struct Person {
  char* name;
  char* addr;
};
struct Student {
  char* name;  // from Person
  char* addr;  // from Person
};
struct Faculty {
  char* name;  // from Person
  char* addr;  // from Person
};
struct ResearchAssistant {
  char* name;  // from Person, Student&Faculty (joined)
  char* addr;  // from Person, no renaming
  char* student_addr;  // from Student and renaming
  char* faculty_addr;  // from Faculty and renaming
};
```

Rule 1 (remove reference identity)**.** *To fix the loophole, first we remove the reference identity relationship among all the renamed fields.*

For example, all the three `*addr` fields in the above example.

When a RESEARCH_ASSISTANT is passed as a PERSON object to a method call or assignment target, and then need to access its `addr` field, depending on its execution context (which we will explain later), this *field access* need to be dispatched to one of:

- `ResearchAssistant.addr`
- `ResearchAssistant.student_addr`
- `ResearchAssistant.faculty_addr`

3.2 Virtual field, and its accessing rules

In traditional OOP languages, we have virtual method dispatch depends on the actual object type, but here the *field access* also needs to be dispatched to the intended renamed new field. Therefore, we would like to introduce the following concept:

Definition 3 (virtual field)**.** If a class field is renamed (anywhere) in the inheritance DAG, we call it a *virtual field*.

For *unplanned* MI, i.e. the programmer can inherit any existing class, and make any feature (here field) adaptations to create a new class, so any field in any class can be a virtual field. To fix the loophole, we introduce the following enhanced compiler rules:

Rule 2 (virtual field accessor rule)**.**

(1) *the programmer must* add new semantic assigning *accessor methods for every virtual field in each class that is immediately below the field's semantic branching site.*
(2) *at each renaming site of a field, the programmer must* override *the new virtual semantic assigning accessor method of that field added in (1), to use the field with the new name.*
(3) *only accessor methods can make direct access (read or write) to those actual fields; while any other methods must use these semantic accessor methods to access those actual fields, instead of accessing those actual fields directly.*

For examples:

- by Rule 2.(1): PERSON is the semantic branching site of field `addr`, so
  - STUDENT must add new accessors get / set_student_addr()
  - FACULTY must add new accessors get / set_faculty_addr()
- by Rule 2.(2): RESEARCH_ASSISTANT is the renaming site, so it must override
  - STUDENT.get / set_student_addr() to read / write the renamed field `student_addr`
  - FACULTY.get / set_faculty_addr() to read / write the renamed field `faculty_addr`

Adding new semantic assigning accessors is very important: e.g.

- FACULTY.get_addr() / set_addr() (via PERSON) v.s.
- FACULTY.get_faculty_addr() / set_faculty_addr()

if we only override get_addr() / set_addr() in RESEARCH_ASSISTANT, it will affect both FACULTY and STUDENT class' methods that calls get_addr() / set_addr(), hence still mix the two different semantics; while adding and overriding get_faculty_addr() can establish the semantics of the renamed field FACULTY.addr → RESEARCH_ASSISTANT.faculty_addr.

Furthermore for any other method defined in FACULTY that need the `faculty_addr` semantics of field `addr` (which was only renamed and available in class RESEARCH_ASSISTANT level and down below), it needs to call these new accessor methods instead of the FACULTY.get_addr() / set_addr().

Now let's update class RESEARCH_ASSISTANT to comply with these rules:

Listing 9. research_assistant.e with virtual accessor method override

```
class RESEARCH_ASSISTANT
inherit
        STUDENT rename addr as student_addr      -- field student_addr inherit the dorm semantics
                redefine get_student_addr, set_student_addr
        end
        FACULTY rename addr as faculty_addr      -- field faculty_addr inherit the lab  semantics
                redefine get_faculty_addr, set_faculty_addr
        end
        -- then select, NOTE: not need by SmartEiffel, but needed by GOBO and ISE compiler
        PERSON  select addr end

create {ANY}
   make

feature {ANY}
   get_student_addr():STRING is  do Result := student_addr end  -- override and read the renamed field!
   get_faculty_addr():STRING is  do Result := faculty_addr end  -- override and read the renamed field!
   set_student_addr(a:STRING) is do student_addr := a end   -- override and write to the renamed field!
   set_faculty_addr(a:STRING) is do faculty_addr := a end   -- override and write to the renamed field!

   print_ra() is  -- print out all 3 addresses
     do
       io.put_string(name +" has 3 addresses: <"+ addr +", "+ student_addr +", "+ faculty_addr + ">%N")
     end
```

```
25
26      make is
27        do
28          name := "ResAssis"
29          addr := "home"             -- the home semantics
30          set_student_addr("dorm")   -- the dorm semantics
31          set_faculty_addr("lab")    -- the lab  semantics
32        end
33  end
```

Please pay special attention to the redefined (override) methods get_student_addr(), get_faculty_addr(), set_student_addr() and set_faculty_addr() to see how they implemented the renamed field's *intended* accessor semantics. With these manual overrides, let's run the updated program, and check the new results:

As we noted in Listing 6, the ISE compiler implemented the problematic reference identity semantics of the renamed fields, *since we cannot change their compiler, our method is not applicable to the ISE compiler*. On the other hand, both GOBO and SmartEiffel do not use this reference identity semantics, so we can check their new outputs.

Listing 10. GOBO: most problems fixed

```
ResAssis has 3 addresses: <home, dorm, lab>
PERSON  size: 24
STUDENT size: 24
FACULTY size: 24
RESEARCH_ASSISTANT size: 40
ResAssis do_benchwork in the: lab
ResAssis take_rest in the: dorm
-- print_student|faculty_addr_direct_field
ResAssis as STUDENT.addr: home
ResAssis as FACULTY.addr: home
-- print_student|faculty_addr_via_accessor
ResAssis as STUDENT.addr: dorm
ResAssis as FACULTY.addr: lab
-- check reference identity
ra.addr != ra.faculty_addr
ra.addr != ra.student_addr
ra.student_addr != ra.faculty_addr
-- test: suppose ra moved both lab2 and dorm2
ResAssis has 3 addresses: <home, dorm, lab2>
ResAssis has 3 addresses: <home, dorm2, lab2>
```

Listing 11. SmartEiffel: most problems fixed

```
1  ResAssis has 3 addresses: <home, dorm, lab>
2  PERSON  size: 12
3  STUDENT size: 12
4  FACULTY size: 12
5  RESEARCH_ASSISTANT size: 20
6  ResAssis do_benchwork in the: lab
7  ResAssis take_rest in the: dorm
8  -- print_student|faculty_addr_direct_field
9  ResAssis as STUDENT.addr: home
10 ResAssis as FACULTY.addr: home
11 -- print_student|faculty_addr_via_accessor
12 ResAssis as STUDENT.addr: dorm
13 ResAssis as FACULTY.addr: lab
14 -- check reference identity
15 ra.addr != ra.faculty_addr
16 ra.addr != ra.student_addr
17 ra.student_addr != ra.faculty_addr
18 -- test: suppose ra moved both lab2 and dorm2
19 ResAssis has 3 addresses: <home, dorm, lab2>
20 ResAssis has 3 addresses: <home, dorm2, lab2>
```

With GOBO Eiffel compiler, most of the problems are fixed, except the two lines 9 & 10 in the middle where the programmer made direct field access (which violates the new programming rules); and again, SmartEiffel's new output is the same as GOBO Eiffel.

Note, even without direct field access, it's better for a non-accessor method to call only accessor method defined in the *same* class, for example, suppose:

Listing 12. problematical call to accessor method from the base class

```
class FACULTY
  do_benchwork() is
    do
      io.put_string(name + " do_benchwork in the: " + get_addr() + "%N");  -- i.e PERSON.get_addr()
    end
```

- FACULTY.do_benchwork() directly call accessor PERSON.get_addr() (instead of FACULTY.get_faculty_addr()), and
- STUDENT.take_rest() directly call PERSON.get_addr() (instead of STUDENT .get_student_addr())

that will be a programming error, since no matter how RESEARCH_ASSISTANT.get_addr() is implemented (or even not overridden at all), there can only be one implementation in

RESEARCH_ASSISTANT, so at least one of RESEARCH_ASSISTANT.do_benchwork() and RESEARCH_ASSISTANT.take_rest() will get a wrong address.

Therefore we add the following accessor calling level rule:

Rule 3 (virtual field accessor calling level warning rule – i.e. violations are warnings instead of errors)**.**

(1) *only accessor method can call super-class' accessor method: e.g. FACULTY.get_faculty_addr() call PERSON.get_addr()*
(2) *any non-accessor method can only call virtual field accessor method defined in the* same *class*

But sometimes, the programmers do need to make direct field access or call accessor methods from the base classes, too much such warning messages can be annoying. Therefore we also introduce a new syntax for such cases to silence the compiler warning messages:

Rule 4 (programmer manually verified direct field access or accessor method from the base class)**.** *new feature access operator !:*

- `object!direct_field_access` *or*
- `object!accessor_method_from_base_class()`

3.3 One step further beyond manual fix

The compiler can be enhanced to issue error / warning messages when detecting these rule violations, and alert the programmer to check and fix them just as we did in our example. While this process works, the programmer needs to re-exam *manually* all the existing code to ensure their semantics are correct.

Eiffel first appeared in 1986, and won the ACM software system awards in 2006, there are many existing users[13] with a possible very big code base. Re-exam and fix all these code base manually is a very complex task, can we do better to avoid this tedious manual approach and make the existing code work *as it is*? The main purpose of MI is to encourage code reuse, we would like to make the method FACULTY.do_benchwork() work correctly according to the programmer's intention *without* adding the extra virtual accessor as we introduced in this section.

Another method is to change the compiler to implement the intended semantics of the rename fields, in the next section we will introduce a new concept called: *rename dispatching based on view stacks* to fix the loophole.

4 RENAME DISPATCHING BASED ON VIEW STACK

(Note: in the following sections, code listings are for language design discussion purpose, hence may not be compilable or executable. The new method we will introduce in this section is independent of the previous section; in fact, we assume the previous section, in particular the updated research_assistant.e listing 9 with virtual accessor override does not exist at all. We only assume Eiffel's reference identity semantics of renamed field is *removed*.)

For any new method implemented in class RESEARCH_ASSISTANT (and its descendants) which is related to its FACULTY role, it can use the renamed new field `faculty_addr`, but how about *existing* methods inherited from the super-classes e.g. FACULTY.do_benchwork() method in Listing 3, which accesses the original field via the old name `addr`?

[13]For example, https://www.eiffel.com/company/customers/ listed even many heavy-weight industry customers ranging from aerospace defense (e.g. Boeing Co), to finance (e.g. CBOE), and to tele-communications (e.g. Alcatel-Lucent), etc.

4.1 Virtual field access dispatch

Ideally, when a super-class's method e.g `FACULTY.do_benchwork()` is called on a `RESEARCH_ASSISTANT` object, the method needs to access the renamed `addr` field with "lab" semantics, i.e `RESEARCH_ASSISTANT.faculty_addr` as the programmer introduced in the renaming clause. However in the current Eiffel, it still accesses the old field `PERSON.addr` which has "home" semantics; similarly `STUDENT.take_rest()` also wrongly access the field `PERSON.addr` in `RESEARCH_ASSISTANT`, whose "home" semantics is not what `take_rest()` expected "dorm" semantics. So we end up in the situation that these two methods from different super-classes which expect different semantics of `addr` still *share* the same field `RESEARCH_ASSISTANT.addr`, and this does not achieve feature separation at all.

So after a feature renaming, when an inherited method is called on a derived class object, it still accesses the original feature by the *old* name, which generates problematic semantics different from the programmer's intention by using renaming. The needed dispatch to the features with *new* names is neither discussed in the existing Eiffel language literature, nor implemented by any of the Eiffel compilers that we have tested. What needed is a semantical dispatch of renamed field, so we introduce the following principle:

Definition 4 (semantical dispatch principle of renamed features)**.** the purpose of feature renaming is to resolve feature name clash while achieving the programmer's renaming intention; when the original feature (by the old name) is accessed (both read and write) on a sub-class object in the super-class' method, that feature access needs to be dispatched to the renamed feature (by the new name) in the sub-class.

This renamed feature dispatching semantics is different from Eiffel's original reference identity semantics: e.g. with reference identity semantics, all these three notation

(1) `RESEARCH_ASSISTANT.addr`
(2) `RESEARCH_ASSISTANT.student_addr`
(3) `RESEARCH_ASSISTANT.faculty_addr`

refer to the same field; while with renamed feature dispatching semantics these three are *separated* fields (with different physical memory locations), and for any method call or statement that need access to the `addr` field, if the execution context is in the:

(1) PERSON branch, it needs to be dispatched to `RESEARCH_ASSISTANT.addr`
(2) STUDENT branch, it needs to be dispatched to `RESEARCH_ASSISTANT.student_addr`
(3) FACULTY branch, it needs to be dispatched to `RESEARCH_ASSISTANT.faculty_addr`

4.2 Field access context is object view stack dependent

In this subsection we will show that field access context is object view stack dependent.

4.2.1 execution context: call stack.

Let's exam the execution context when `STUDENT.set_student_addr()` is called on a `RESEARCH_ASSISTANT` object: the method is defined in class STUDENT.e in Listing 2, which in turn calls `PERSON.set_addr()` method, and the final assignment statement there writes to the `addr` field, so the call stack at the assignment site is (from the top to the bottom)[14]:

Listing 13. the actual call stack of ra.set_student_addr()

```
set_addr()          --  PERSON.e line 9  with Current type: PERSON
set_student_addr()  -- STUDENT.e line 6, with Current type: STUDENT
```

[14]The Eiffel keyword `Current` is just like `this` in C++ & Java, or `self` in Python, which represents the current object instance.

```
ra.set_student_addr("dorm")          -- with Current type: RESEARCH_ASSISTANT
```

As we have just discussed, this write needs to be performed on the `student_addr` field of `RESEARCH_ASSISTANT` (please refer to the renaming DAG of Fig 2) hence[15]:

Listing 14. write to the renamed field

```
1  ra.set_student_addr("dorm");         -- write to the STUDENT.addr field
2  assert(ra.student_addr == "dorm");   -- read the renamed student_addr field
3
4  ra.set_faculty_addr("lab");          -- write to the FACULTY.addr field
5  assert(ra.faculty_addr == "lab");    -- read the renamed faculty_addr field
```

For line 1: the actual assignment statement to the field `(PERSON.)addr` is in the method `PERSON.set_addr()`, and at that assignment site (i.e. line 9 of PERSON.e of Listing 1), the call stack of the `Current` object's type from bottom to the top is:

$$\text{callStackTypes} = [\text{RESEARCH\_ASSISTANT}, \text{STUDENT}, \text{PERSON}]$$

For line 4: similarly the call stack is:

$$\text{callStackTypes} = [\text{RESEARCH\_ASSISTANT}, \text{FACULTY}, \text{PERSON}]$$

Note the *same* (by-name) field `PERSON.addr` is modified by the *same* method `PERSON.set_addr()`, and is invoked on the *same* object (`ra`), but the actual assignments need to be made on two *different* actual fields: `ra.student_addr` or `ra.faculty_addr`, due to the different call stacks. Conversely, to read a renamed field e.g. `ra.get_student_addr()`, the actual call stack is:

Listing 15. the actual *call stack* of ra.get_student_addr()

```
get_addr()          --  PERSON.e line 8  with Current type: PERSON
get_student_addr()  -- STUDENT.e line 5, with Current type: STUDENT
ra.get_student_addr()                    -- with Current type: RESEARCH_ASSISTANT
```

and the *actual* field which is needed to be read here is `ra.student_addr`.

4.2.2 *execution context: view stack.*

Now, let's consider the following assignment statements sequence:

Listing 16. assignment chain, and *view stack*

```
1  ra: RESEARCH_ASSISTANT;
2  ra_as_student: STUDENT := ra;
3  ra_as_student_as_person: PERSON := ra_as_student;
4  ra_as_student_as_person.addr := "dorm";
```

At the last line 4, the actual assignment site, there is no method call stack; however, compare it with the previous code listing 13 of the *call stack* there, the variable `ra_as_student_as_person` here has a *view stack* of the object `ra` it holds:

$$\text{viewStackTypes} = [\text{RESEARCH\_ASSISTANT}, \text{STUDENT}, \text{PERSON}]$$

[15]Here we use "==" to mean reference identity testing (as in C++/Java).

Definition 5 (object view stack)**.** We generalize the concept of method call stack to *object view stack*, at the bottom of the stack is the object's actual type RESEARCH_ASSISTANT, and the `ra` object is assigned to variable `ra_as_student` of type STUDENT, and then to `ra_as_student_as_person` of type PERSON. At this point, the object is used (viewed) as if it's a PERSON type thru a stack of lenses all the way down to the actual object of type RESEARCH_ASSISTANT.

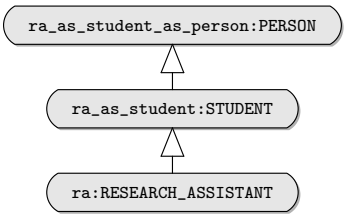

Fig. 3. view stack as a set of "lenses" on the object `ra`

Example 4.1. In the following, the same `RESEARCH_ASSISTANT ra` object is held by different variables of its super-class type, hence has different view stacks:

Listing 17. different views of the same object, direct field access

```
1   ra: RESEARCH_ASSISTANT  -- all the variables refer to this same RESEARCH_ASSISTANT object
2   ra_as_student: STUDENT := ra;
3   ra_as_faculty: FACULTY := ra;
4   person: PERSON := ra;
5
6   -- accessing the field by the same name does not mean accessing the same field!
7   assert(ra_as_student.addr == "dorm");  -- [RESEARCH_ASSISTANT, STUDENT] view of ra object
8   assert(ra_as_faculty.addr == "lab" );  -- [RESEARCH_ASSISTANT, FACULTY] view of ra object
9   assert(person.addr == "home");         -- [RESEARCH_ASSISTANT, PERSON]  view of ra object
10
11  -- view stack of assignment chain
12  person := ra_as_student;               -- assign ra to PERSON via STUDENT
13  assert(person.addr == "dorm");         -- [RESEARCH_ASSISTANT, STUDENT, PERSON] view of ra object
14
15  person := ra_as_faculty;               -- assign ra to PERSON via FACULTY
16  assert(person.addr == "lab" );         -- [RESEARCH_ASSISTANT, FACULTY, PERSON] view of ra object
```

note on line 13, assert(person.addr == "dorm"); while on line 16, assert(person.addr == "lab"). This shows view stack is different from usual method call stack, i.e. even in the same scope assigning to a local variable of a different type will change the view stack of the object.

Summary: every access (write and read) of a renamed field needs to be dispatched based on its renaming DAG, *and* the view stacks of the variable at the access site. To the best of the author's knowledge, this behavior has never been documented in any previous OOP literature. We call it *rename dispatching based on the view stack*.

Example 4.2. As a consequence of such renamed field dispatch, now the following accessor method calls will return the intended renamed field:

Listing 18. different views of the same object, accessor method call

```
ra_as_student.get_addr();  -- now return "dorm"
ra_as_faculty.get_addr();  -- now return "lab"
       person.get_addr();  -- now return "home"
```

which means we can make the existing code work as it is by adding rename dispatching to the compiler.

4.3 Implementation: variable as object and view stack holder

An object can be hold by different variables, and each variable hold a different view (history) of the object. For example, a same `RESEARCH_ASSISTANT` object can be passed to both the methods call `do_benchwork()` and `take_rest()` simultaneously, e.g on two different threads. So the view stack cannot be hold by the object itself (then will be shared by two different threads); instead each execution context need to maintain its own separate view stack of the object.

Definition 6. Each variable is a "fat pointer", which has two components:

(1) the actual object
(2) the view stack of the object

And we introduce the following rules to update view stacks:

Rule 5 (view stack updating rule)**.** *Note, in the following rules,* variables *also include compiler generated temporary variables (not visible by the programmer)*

(1) *object creation: var:V = new O(), when an object of type O is created and assigned to var of type V, then*

$$view\_stack(var) = [O,\ V]$$

(2) *assignment: var:V = u, when a variable u is assigned to a variable of type V, then*

$$view\_stack(var) = view\_stack(u) + [V]$$

i.e, push type V on to the top of the view stack.

(3) *function call: function(var:V) be called as function(u), when a variable u is passed to a function as a parameter of type V, then*

$$view\_stack(var) = view\_stack(u) + [V]$$

i.e. push type V on to the top of the view stack.

Example 4.3 (assignment chain). `ra` is first assigned to `ra_as_student`, and then to `person`, then:

view_stack(person) = [RESEARCH_ASSISTANT, STUDENT, PERSON]

4.4 rename dispatching

Each variable carries a type stack, which holds the type information of the object's view history.

Rule 6 (Virtual field dispatching rule)**.** *Given an object's view stack S, find the shortest path P in the object's field's renaming DAG from the top(S) to the bottom(S), such that* $S \subseteq reverse(P)$*,*

(1) *if there is only one shortest path, dispatch to the field's final rename in the renaming DAG.*
(2) *if there are multiple such shortest paths, raise a run-time exception.*

Now let us review our previous write and read access to the virtual field `addr`:

Example 4.4.

(1) In Listing 13, at the assignment site (line 9 of class PERSON in Listing 1):

view_stack(Current) = [RESEARCH_ASSISTANT, STUDENT, PERSON]

we can find the corresponding path in Fig 2 of the renaming DAG of field `addr` is:

PERSON →STUDENT →RESEARCH_ASSISTANT

and the final name of the field is `student_addr`, so the assignment of string "dorm" in set_addr() to virtual field `addr` will be made on the actual field `ra.student_addr`.

(2) and for line 7 of Listing 17,

view_stack(ra_as_student) = [RESEARCH_ASSISTANT, STUDENT]

we can find the corresponding path in Fig 2 of the renaming DAG of field `addr` is:

STUDENT →RESEARCH_ASSISTANT

and the final name of the field is `student_addr`, so the field access of virtual field `addr` will be dispatched to the actual field `ra.student_addr`, thus the assertion holds:

```
assert(ra_as_student.addr == "dorm");  --  [RESEARCH_ASSISTANT, STUDENT] view of ra object
```

4.5 Normalized view stacks, and dispatch optimization

With multiple inheritance, an object's view stack can be more complex than just along a single linear branch, let's consider the following MI DAG: suppose there is an object of type Child, this object can be assigned (with compiler generated type checking) to a reference variable of any of its base class type, and in any sequence. In Eiffel this is called assignment attempt, and in other languages (e.g. C++ / Java) it is called (type checked) cast. For example, consider the following assignment attempts:

Listing 19. type cast

```
1  child: Child
2  base_b: Base_B
3  derived_a: Derived_A
4
5  base_b := child
6  derived_a ?= base_b  -- type cast
7  if derived_a /= Void then
8    derived_a.some_method_call()
9  end
```

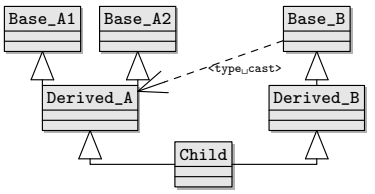

Fig. 4. type cast from Base_B to Derived_A

all the assignment attempts will succeed, so the view_stack(derived_a) at line 8 is [Child, Base_B, Derived_A], and in particular Base_B can be totally unrelated to Derived_A. This example shows in MI, it is possible to cast to a variable of type A which is on a *different* branch in the inheritance DAG from the object's current holding variable's declaration type B. To simplify view stack management, let's define the *normalized* view stack:

Definition 7 (Normalized view stack)**.** Let view stack

$$S = [T_0, T_1, \ldots T_{n-1}]$$

and T_0 be the object's actual type at the bottom of the stack, we say S is a normalized stack, if for any $j > i$, T_j is a superclass of T_i. Or in short, all the types in a normalized view stack needs to be in the strict monotonic super-classing total order.

To normalize an arbitrary view stack, we introduce the following rules:

Rule 7. *If two adjacent elements of the view stack are the same [A, A], normalize it to [A].*

Rule 8 (type cast)**.** *Suppose [A, B] are the top two elements of a view stack, i.e. VS + [A, B], then update the view stack:*

(1) *first cast to the* greatest common derived class *gcd(A, B) of A and B: VS + [gcd(A, B)]*
(2) *then cast from gcd(A, B) to B: VS + [gcd(A, B) + B]*

Example 4.5. normalize view stack [RA, FACULTY, STUDENT]:

(1) $[RA, RA]$, since RA is the gcd(FACULTY, STUDENT)
(2) $[RA, RA, STUDENT]$
(3) $[RA, STUDENT]$

Example 4.6. cast up and down along the same branch: normalize view stack [RA, FACULTY, RA]

(1) $[RA, RA]$, since RA is the gcd(FACULTY, RA)
(2) $[RA]$

The normalized view stack can only effectively grow in the direction to the root class of the inheritance DAG.

Theorem 4.7 (limited view stack length). *The max view stack length is the max depth of the inheritance DAG.*

The most straightforward implementation of the dispatch method is at least linear to the stack length; to speed up, we can create a hash-table by enumerating all the possible type view stacks during the compilation, and reduce the runtime dispatching cost to O(1) (since both the full inheritance and field renaming DAG are known at compile time, the compiler can create a perfect hash-table).

Rule 9 (Repeated inheritance rewrite)**.** *Repeated inheritance can be easily supported by the following simple rewrite rule:*

```
class B inherit A, A   -- repeatedly inherit A multiple times by the same sub-class is not allowed!

-- but, we can rewrite to
class A1 inherit A
class B  inherit A, A1  -- this is fine
```

5 IMPLEMENTATION: VIRTUAL FIELD DISPATCH BASED ON VIEW STACKS

Due to paper length limit, the specifics of our implementation of what we discussed in the previous section, and the full code of demo.yi (which is equivalent of the Eiffel code of Section 2), are in the Supplementary Material A. Our new output is:

As we can see, the results are all what the programmer has expected now. We also demonstrate *on purpose* that two distinct fields `Student._student_age` and `Faculty._faculty_age` are joined into one single field `ResearchAssistant._age`, which the three Eiffel compilers all failed to join with the message: "Error: two or more features have the same name (age)."

Listing 20. demo.yi output

```
ResAsst has 3 addresses: <home dorm lab>
ResAsst do_benchwork in the: lab
ResAsst take_rest in the: dorm
-- print_student|faculty_addr_direct_field
ResAsst as STUDENT.addr: dorm, age=18
ResAsst as FACULTY.addr: lab, age=18
-- print_student|faculty_addr_via_accessor
ResAsst as STUDENT.addr: dorm
ResAsst as FACULTY.addr: lab
-- test: suppose ra moved both lab2 and dorm2
ResAsst has 3 addresses: <home dorm lab2>
ResAsst has 3 addresses: <home dorm2 lab2>
```

5.1 Legacy Eiffel code migration plan: combine the two methods

As we can see in this second method, every field access (except the raw access operator with "!") becomes a method call, and for every variable assignment (including parameter passing in method call) the language runtime needs to maintain the object view stacks. These operations will increase both the memory and runtime overhead of the compiled program. While the first method we introduced in the previous Section 3 is more efficient at runtime. Actually to migrate legacy Eiffel code, we can combine these two methods:

(1) first, use the second method of this section enhanced compiler to generate test cases for the intended semantics.
(2) then, auto generate new and override semantic assigning accessor methods according to Rule 2 & 3 for the corresponding virtual fields, and use the first method enhanced compiler to validate these test cases,

6 DISCUSSIONS

6.1 Renamed methods: dispatch first by view stack then by virtual table

In Eiffel, methods can also be renamed, and the renamed methods need to be treated in the same way as renamed fields.

In 2015, an Eiffel programmer found and raised a similar question regarding renamed methods on the web: https://stackoverflow.com/questions/32498860/

> I am struggling to understand the interplay of multiple inheritance with replication and polymorphism. Please consider the following classes forming a classical diamond pattern.
>
> If I attach an instance of D to an object `ob_as_c` of type C, then `ob_as_c.c` prints "c" as expected. However, if attach the instance to an object `ob_as_b` of type B, then `ob_as_b.b` will also print "c".
>
> Is this intended behavior? Obviously, I would like `ob_as_b.b` to print "b".

```
deferred class A
  feature
    a  deferred end
  end

deferred class B
  inherit A
    rename a as b end
  end

deferred class C
  inherit A
    rename a as c end
  end

class D
  inherit
    B
    C select c end
feature
  b do print("b") end
  c do print("c") end
end
```

Both Bertrand Meyer and Emmanuel Stapf (the lead developer of EiffelStudio) replied to that question, but they only mentioned that in (virtual) dynamic binding, there is only one version of the method on D, can be called.

Instead we think, firstly, this is another problem in Eiffel's `select` clause as we have mentioned earlier: after the two feature renamings (separation) there is *no* more name clash on `a`, however they are forced to be joined again (by the `inherit C select c`), i.e `ob_as_b.b` actually calls `d.c`. As the programmer who asked question finally put it: "Unfortunately, this makes Eiffel's inheritance features much less useful to me."

Secondly, just same as our treatment of virtual fields: the compiler should keep methods `D.b & D.c` separate, and the `select` clause is no longer needed. Now dispatch to `ob_as_b.b`, `ob_as_c.c` and even `ob_as_a.a` by the renaming DAG and the view stack first, and then dispatch as a virtual method (if there is any further override), as we did in Section 4. This will achieve what the user wanted in the original question.

6.2 Compare virtual method dispatch and rename dispatching

Virtual *field* dispatch is different from virtual *method* dispatch in that virtual field dispatch depends on *the whole view stack* from the holding variable type down to the actual object type; while virtual method dispatch depends on *only* the actual object type.

7 RELATED WORK

There is a long history of inheritance and polymorphism have been studied since 1980s, and there are copious literature on multiple inheritance, e.g. [Compagnoni and Pierce. 1993], [Cardelli 1988], [van Limberghen and Mens 1996], [Taivalsaari 1996], [Bracha and Cook 1990]. In the following we will only compare some of the earlier work that has some similarity as our work, and highlight the difference.

In [Carré and Geib 1990] Carré and Geib introduced the point-of-view (PoV) notion of multiple inheritance. While both their work and our work try to solve the same problem of dynamic dispatching of class fields, our work differs from their PoV in the following ways:

(1) Our view stack approach dynamically tracks the *full object-to-target runtime path*, while their approach only considers the <source object, target type> *two points pair*.
(2) In their paper, they did not give the detailed rules on *how* to do selection (i.e dispatch), especially if there are *multiple paths* between PoV<C, O>, (and its even not clear if they handle such cases at all); while we give very specific Rule 5 on how to dispatch, even for *multiple paths*.
(3) Their approach only uses the *global* inheritance lattice for *all* the Pov(C, O) calculation; while in our approach, *each renamed field has its own renaming DAG* (which can be different from the global inheritance DAG), so in our stack view dispatch calculation we use each fields own renaming DAG (and for never-renamed field, e.g. `name`, there is no need for dispatch).
(4) In their approach, all inherited fields are separated; while in our approach fields can be shared or separated (renamed) according to the programmers application semantics.

In [Chambers et al. 1982], the sender path tiebreaker rule of SELF can only handle the case where if "only one of the parents is an ancestor or descendant of the object containing the method that is sending the message (the sending method holder)", which means this rule cannot handle the inheritance relationship in the diamond problem, while our approach can handle it.

In [Borning and Ingalls 1982], Borning and Ingalls discussed the multiple inheritance in Smalltalk-80. They also considered when the same method is inherited via several paths, an error will be reported to the user. In their paper, they did not give the detail of the method resolution method that they used. While our approach gives every specific rules on how to do runtime dispatch, and when to raise exceptions.

In [Burow et al. 2018], an orthogonal policy Object Type Integrity (OTI) is proposed to dynamically track C++ object types. So instead of allowing a set of targets for each dynamic dispatch on an object, only the single, correct target for the objects type is allowed. Their work is based on C++ class model where there is no feature renaming, while our work is toward fixing Eiffel's renaming mechanism.

In [Ngomo 2021], Ngomo described a non-linear and non-deterministic approach of the semantics of multiple inheritance in their problem domain, i.e. multiple specification of logical objects. While our approach is deterministic, so the programmers can easily reason about the programs.

In [Suchánek and Pergl 2020], Suchánek and Pergl studied the method resolution order in Python, and showed that inheritance can be implemented with minimisation of combinatorial effect using the patterns.

8 CONCLUSIONS

We found the reference identity semantics of Eiffel's field renaming mechanism is problematic, as demonstrated in the diamond problem of MI. We introduced a new concept called virtual field and proposed two methods to solve it:

(1) always add new and use semantic assigning accessors, avoid direct field access.
(2) rename dispatching based on view stack.

Some future work directions:

- On the theoretical aspects: study the interplay of virtual fields with other language constructs. In OOP virtual method is a well studied concept, while we have not found any discussion of virtual field. The interplay of virtual field with other constructs of the OOP language is yet to be explored for new opportunities (or new problems).
- On the practical aspects: design more efficient implementations. Design and implement more efficient management strategy to reduce view stack memory requirement and dispatch runtime overhead.

A SUPPLEMENTARY MATERIAL

All the source code of this paper can be found in the supplementary material: eiffel_rename.tgz, including the demo of the Eiffel rename loophole we found, the two proposed fixing methods, and the detailed description doc vfield_sup.pdf.

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