



Master's Thesis

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Design and Implementation of Dynamic Memory Management in a Reversible Object-Oriented Programming Language

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Abstract

The reversible object-oriented programming language (ROOPL) was presented in late 2016 and proved that object-oriented programming paradigms works in the reversible setting. The language featured simple statically scoped objects which made non-trivial programs tedious, if not impossible to write using the limited tools provided. We introduce an extension to ROOPL in form the new language ROOPL++, featuring dynamic memory management and fixed-sized arrays for increased language expressiveness. The language is a superset of ROOPL and has formally been defined by its language semantics, type system and computational universality. Considerations for reversible memory manager layouts are discussed and ultimately lead to the selection of the Buddy Memory layout. Translations of the extensions added in ROOPL++ to the reversible assembly language PISA are presented to provide garbage-free computations. The dynamic memory management extension successfully increases the expressiveness of ROOPL and as a result, shows that non-trivial reversible data structures, such as binary trees and doubly-linked lists, are feasible and do not contradict the reversible computing paradigm.

Preface

This Master's Thesis is submitted as the last part for the degree of Master of Science in Computer Science at the University of Copenhagen, Department of Computer Science, presenting a 30 ECTS workload.

The thesis consists of 231 pages and a ZIP archive containing source code and test programs developed as part of the thesis work.

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Introduction

In recent years, technologies such as cloud-based services, deep learning, cryptocurrency mining and other services requiring large computational power and availability have been on the rise. Most of these services are hosted on massive server parks, consuming immense amounts of electricity in order to power the machines and the cooling architectures as heat dissipates from the hardware. A recent study showed that the Bitcoin network including its mining processes' currently stands at 0.13% of the total global electricity consumption, rivaling the usage of a small country like Denmark's [6]. With the recent years focus on climate and particularly energy consumption, companies have started to attempt to reduce their power usage in these massive server farms. As an example, Facebook built new server park in the arctic circle in 2013, in an attempt to take advantage of the natural surroundings in the cooling architecture to reduce its power consumption [24].

Reversible computing presents a possible solution the problematic power consumption issues revolving around computations. Traditional, irreversible computers dissipates heat during their computation. Landauer's principle states that deletion of information in a system always results by an increase in energy consumption. In reversible computing, all information is preserved throughout the execution, and as such, the energy consumption theoretically should be smaller [14].

Currently, reversible computing is not commercially appealing, as it is an area which still is being actively researched. However, several steps has been taken in the direction of a fully reversible system, which some day might be applicable in a large setting. Reversible machine architectures have been presented such as the Pendulum architecture and its instruction set Pendulum ISA (PISA) [26, 3] and the BOBISA architecture and instruction set [23] and high level languages JANUS [16, 31, 29] and R [7] exists.

While cryptocurrency mining and many other computations are not reversible, the area remains interesting in terms of its applications and gains.

1.1 Reversible Computing

Reversible computing is a two-directional computational model in which all processes are time-invertible. This means, that at any time during execution, the computation can return to a former state. In order to maintain *reversibility*, the reversible computational model cannot compute *many-to-one* functions, as the models requires an exact inverse f^{-1} of a function f in order to

support backwards determinism. Therefore, reversible programs must only consist of *one-to-one* functions, also known as *injective* functions, which result in a garbage-free computation, as garbage-generating functions simply can be unwinded to clean up.

Each step of a reversible program is locally invertible, meaning each step has exactly one inverse step. A reversible program can be inverted simply by computing the inverse of each of its steps, without any knowledge about the overall functionality or requirements of the program. This property immediately yields interesting consequences in terms of software development, as an encryption or compression algorithm implemented in a reversible language immediately yields the decryption or decompression algorithm by running the algorithm backwards.

The reversibility is however not free and comes at the cost of strictness when writing programs. Almost every popular, irreversible programming language features a conditional component in form of **if-else**-statements. In these languages, we only define the *entry*-condition in the conditional, that is, the condition that determines which branch of the component we continue execution in. In reversible languages, we must also specify an *exit*-condition, such that we can determine which branch we should follow, when executing the program in reverse. In theory, this sounds trivial, but in practice it turns to add a new layer of complexity when writing programs.

1.2 Object-Oriented Programming

Object-oriented programming (OOP) has for many years been the most widely used programming paradigm as reflected in the popular usage of object-oriented programming languages, such as the C-family languages, JAVA, PHP and in recent years JAVASCRIPT and PYTHON. The OOP core concepts such as *inheritance*, *encapsulation* and *polymorphism* allows complex systems to be modeled by breaking the system into smaller parts in form of abstract objects [17].

1.3 Reversible Object-Oriented Programming

The high-level reversible language ROOPL (Reversible Object-Oriented Programming Language) was introduced in late 2016 [11, 12]. The language extends the design of previously existing reversible imperative languages with object-oriented programming language features such as user-defined data types, class inheritance and subtype-polymorphism. As a first, ROOPL successfully integrates the object-oriented programming (OOP) paradigms into the reversible computation setting using a static memory manager to maintain garbage-free computation, but at cost of programmer usability as objects only lives within **construct** / **deconstruct** blocks, which needs to be predefined, as the program call stack is required to be reset before program termination.

Conceptualizations and ideas for the JOULE language was also published in 2016 [22]. The language, a homonym of JANUS OBJECT-ORIENTED LANGUAGE, JOOL, presented an alternative OOP extension to JANUS, differing from ROOPL. The language featured heap allocated objects with constructors and multiple object references, as such also addressing the problems with ROOPL. The language is still a work in progress, aiming to provide a useful, reversible object oriented-programming language.

1.4 Motivation

The block defined objects of ROOPL and lack of multiple references are problematic when writing complex, reversible programs using OOP methodologies as they pose severe limitations on the expressiveness. It has therefore been proposed to extend and partially redesign the language with dynamic memory management in mind, such that these shortcomings can be addressed, and ultimately increase the usability of reversible OOP. Work within the field of reversible computing related to heap manipulation [2], reference counting [18] and garbage collection [19] suggests that a ROOPL extension is feasible.

1.5 Thesis Statement

An extension of the reversible object-oriented programming language with dynamic memory management is feasible and effective. The resulting expressiveness allows non-trivial reversible programming previously unseen, such as reversible data structures, including linked lists, doubly linked lists and trees.

1.6 Outline

This Master's thesis consists of four chapters, besides the introductory chapter. The following summary describes the following chapters.

- **Chapter 2** formally defines the ROOPL extension exemplified by the new language ROOPL++, a superset of ROOPL.
- **Chapter 3** serves as a brief description of dynamic memory management along with a discussion of various reversible, dynamic memory management layouts.
- **Chapter 4** presents the translation techniques utilized in compiling a ROOPL++ program to PISA instructions.
- **Chapter 5** presents the conclusions of the thesis and future work proposals.

Besides the five chapters, a number of appendices is supplied, containing PISA translations of the reversible heap allocation algorithm, the source code of the ROOPL++ to PISA compiler, the ROOPL++ source code for the example programs and their translated PISA versions.

The ROOPL++ Language

With the design and implementation of the REVERSIBLE OBJECT-ORIENTED PROGRAMMING LANGUAGE (ROOPL) and the work-in-progress report of JOULE, the first steps into the uncharted lands of Object-Oriented Programming (OOP) and reversibility were taken. In this chapter, we present ROOPL++, the natural successor to ROOPL, improving the object instantiation of the language by letting objects live outside **construct/deconstruct** blocks, allowing complex, reversible programs to be written using OOP methodologies. As with its predecessor, ROOPL++ is purely reversible and each component of a program written in ROOPL++ is locally invertible. This ensures no computation history is required, nor added program size for backwards program execution.

Inspired by other language successors such as C++ was to C, ROOPL++ is a superset of ROOPL, containing all original functionality of its predecessor, extended with new object instantiation methods for increased programming usability and an array type.

```

1 class Fib
2   int[] xs
3
4   method init()
5     new int[2] xs
6
7   method fib(int n)
8     if n = 0 then
9       xs[0] ^= 1
10      xs[1] ^= 1
11     else
12       n -= 1
13       call fib(n)
14       xs[0] += xs[1]
15       xs[0] <=> xs[1]
16     fi xs[0] = xs[1]
17
18   method get(int out)
19     out ^= xs[1]
20
21 class Program
22   int result
23   int n
24
25   method main()
26     n ^= 4
27
28     new Fib f
29     call f::init()
30     call f::fib(n)
31     call f::get(result)
32     uncall f::fib(n)
33     uncall f::init()
34     delete Fib f

```

Figure 2.1: Example ROOPL++ program implementing the Fibonacci function

2.1 Syntax

A ROOPL++ program consists, analogously to a ROOPL program, of one or more class definitions, each with a varying number of fields and class methods. The entry point of the program is a nullary main method, which is defined exactly once and is instantiated during program start-up. Fields of the main object will serve as output of the program, just as in ROOPL.

ROOPL++ Grammar

$prog$	$::= cl^+$	(program)
cl	$::= \text{class } c \text{ (inherits } c)^? (t\ x)^* m^+$	(class definition)
d	$::= c \mid c[e] \mid \text{int}[e]$	(class and arrays)
t	$::= \text{int} \mid c \mid \text{int}[] \mid c[]$	(data type)
y	$::= x \mid x[e]$	(variable identifiers)
m	$::= \text{method } q(t\ x, \dots, t\ x)\ s$	(method)
s	$::= y \odot = e \mid y <=> y$	(assignment)
	$\mid \text{if } e \text{ then } s \text{ else } s \text{ fi } e$	(conditional)
	$\mid \text{from } e \text{ do } s \text{ loop } s \text{ until } e$	(loop)
	$\mid \text{construct } c\ x\ s\ \text{destruct } x$	(object block)
	$\mid \text{local } t\ x = e\ s\ \text{delocal } t\ x = e$	(local variable block)
	$\mid \text{new } d\ y \mid \text{delete } d\ y$	(object con- and destruction)
	$\mid \text{copy } d\ y\ y \mid \text{uncopy } d\ y\ y$	(reference con- and destruction)
	$\mid \text{call } q(x, \dots, x) \mid \text{uncall } q(x, \dots, x)$	(local method invocation)
	$\mid \text{call } y::q(x, \dots, x) \mid \text{uncall } y::q(x, \dots, x)$	(method invocation)
	$\mid \text{skip} \mid s\ s$	(statement sequence)
e	$::= \bar{n} \mid x \mid x[e] \mid \text{nil} \mid e \otimes e$	(expression)
\odot	$::= + \mid - \mid ^$	(operator)
\otimes	$::= \odot \mid * \mid / \mid \% \mid \& \mid \mid \&\& \mid \mid < \mid > \mid = \mid != \mid <= \mid >=$	(operator)

Syntax Domains

$prog \in$ Programs	$s \in$ Statements	$n \in$ Constants
$cl \in$ Classes	$e \in$ Expressions	$x \in$ VarIDs
$t \in$ Types	$\odot \in$ ModOps	$q \in$ MethodIDs
$m \in$ Methods	$\otimes \in$ Operators	$c \in$ ClassIDs

Figure 2.2: Syntax domains and EBNF grammar for ROOPL++

The ROOPL++ grammar extends the grammar of ROOPL with a new static integer or class array type and a new object lifetime option in form of objects outside of blocks, using the **new** and

delete approach. Furthermore, the local block extension proposed in [11] has become a standard part of the language. Class definitions remains unchanged, and consists of a **class** keyword followed by a class name. Subclasses must be specified using the **inherits** keyword and a following parent class name. Classes can have any number of fields of any of the data types, including the new Array type. A class definition is required to include at least one method, defined by the **method** keyword followed by a method name, a comma-separated list of parameters and a body.

Reversible assignments for integer variables and integer array elements uses similar syntax as JANUS assignments, by updating a variable through any of the addition (+=), subtraction (-=) or bitwise XOR (^=) operators. As with JANUS, when updating a variable x using any of said operators, the right-hand side of the operator argument must be entirely independent of x to maintain reversibility. Usage of these reversible assignment operators for object or array variables is undefined. Variables and array elements of any type can be swapped using the <=> operator as long as the variable is of same type as the array type. If an array is of a base class type, subclass variable values can be swapped in and out of the array, as long as the resulting value in the variable is still of the original subclass type.

ROOPL++ objects can be instantiated in two ways. Either using object blocks known from ROOPL, or by using the **new** statement. The object-blocks have a statically-scoped lifetime, as the object only exists within the **construct** and **destruct** segments. Using **new** allows the object to live until program termination, if the program terminates with a **delete** call. By design, it is the programmers responsibility to deallocate objects instantiated by the **new** statement.

Arrays are also instantiated by usage of **new** and **delete**. Assignment of array cells depend on the type of the arrays, which is further discussed in section 2.4.

The methodologies for argument aliasing and its restrictions on method on invocations from ROOPL carries over in ROOPL++ and object fields are as such disallowed as arguments to local methods to prevent irreversible updates and non-local method calls to a passed objects are prohibited. The parameter passing scheme remains call-by-reference and the object model of ROOPL remains largely unchanged in ROOPL++.

2.2 Object Instantiation

Object instantiation through the **new** statement follows the pattern of the mechanics known from the **construct/destruct** blocks from ROOPL, but providing improved scoping and lifetime options objects. The mechanisms of the statement

construct c x s **destruct** x

are as follows:

1. Memory for an object of class c is allocated. All fields are automatically zero-initialized by virtue of residing in already zero-cleared memory.
2. The block statement s is executed, with the name x representing a reference to the newly allocated object.

3. The reference x may be modified by swapping its value with that of other references of the same type, but it should be restored to its original value within the statement block s , otherwise the meaning of the object block is undefined.
4. Any state that is accumulated within the object should be cleared or uncomputed before the end of the statement is reached, otherwise the meaning of the object block is undefined.
5. The zero-cleared memory is reclaimed by the system.

The statement pair consisting of

new $c\ x$... **delete** $c\ x$

could be considered a *dynamic* block, meaning we can have overlapping blocks. Compared to **construct/destruct** block consisting of a single statement, the **new/delete** block consist of two separate statements. We can as such initialize an object x of class c and an object y of class d and destroy x before we destroy y , a feature that was not possible in ROOPL. The mechanisms of the **new** statement are as follows:

1. Memory for an object of class c is allocated. All fields are automatically zero-initialized by virtue of residing in already zero-cleared memory.
2. The address of the newly allocated block is stored in the previously defined and zero-cleared reference x .

and the mechanisms of the **delete** statement are as follow

1. The reference x may be modified by swapping its internal field values with that of other references of the same type, but should be zero-cleared before a **delete** statement is called on x , otherwise the meaning of the object deletion is undefined.
2. Any state that is accumulated within the object should be cleared or uncomputed before the **delete** statement is executed, otherwise the meaning of the object block is undefined.
3. The zero-cleared memory is reclaimed by the system.

The mechanisms of the **new** and **delete** statements are, essentially, a split of the mechanisms of the **construct/destruct** blocks into two separate statements. As with ROOPL, fields must be zero-cleared after object deletion, otherwise it is impossible for the system to reclaim the memory reversibly. This is the responsibility of the of the programmer to maintain this, and to ensure that objects are indeed deleted in the first place. A **new** statement without a corresponding **delete** statement targeting the same object further ahead in the program is undefined, as is a delete statement without a preceding **new** statement.

Note that variable scopes are always static, but object scopes can be either static (using **construct/destruct**) or dynamic (using **new/delete**).

2.3 Array Model

Besides asymmetric object lifetimes, ROOPL++ also introduces reversible, fixed-sized arrays of either integer or object types. While ROOPL only featured integers and custom data types in form of classes, one of its main inspirations, JANUS, implemented static, reversible arrays [31].

While ROOPL by design did not include any data storage language constructs, as they are not especially noteworthy nor interesting from an OOP perspective, they do generally improve the expressiveness of the language. Arrays were decided to be part of the core language for this reason, as one of the main goals of ROOPL++ is increased expressiveness while implementing reversible programs.

In ROOPL++, arrays expand upon the array model from JANUS. Arrays are indexed by integers, starting from 0. In JANUS, only integer arrays were allowed, while in ROOPL++ arrays of any type can be defined, meaning either integer arrays or custom data types in form of class arrays. They are however, still restricted to one dimension.

Array element accessing is accomplished using the bracket notation known from JANUS. Accessing an out-of-bounds index is undefined. Array instantiation and element assignments, aliasing and circularity is described in detail in the following section.

Arrays can contain elements of different classes sharing a base class, that is, say class A and B both inherit from some class C and array x is of type $C[]$. In this case, the array can hold elements of type A , B , and C . When swapping array elements from a base class array with object references, the programmer must be careful not to swap the values of, say, and A object into a B reference.

2.4 Array Instantiation

Array instantiation uses the **new** and **delete** keywords to reversibly construct and destruct array types. The mechanisms of the statement

$$\mathbf{new\ int}[e]\ x$$

in which we reserve memory for an integer array are as follows

1. The expression e is evaluated
2. Memory equal to the integer value that e evaluates to and an additional small amount of memory for overhead is reserved for the array.
3. The address of the newly allocated memory is stored in the previously defined and zero-cleared reference x .

In ROOPL++, we only allow instantiation of fixed-sized arrays of a length defined in the given expression e . Array elements are assigned dependent on the type of the array. For integer arrays, any of the reversible assignment operators can be used to assign values to cells. For class arrays, we assign cell elements a little differently. We either make use of the **new** and **delete** statements, but instead of specifying which variable should hold the newly created/deleted object or array,

we specify which array cell it should be stored in or we use the **swap** statement to swap values in and out of array cells. Usage of the assignment operators on non-integer arrays is undefined.

```

1  new int[5] intArray      // Init new integer array
2  new Foo[2] fooArray      // init new Foo array
3
4  intArray[1] += 10         // Legal array integer assignment
5  intArray[1] -= 10         // Legal Zero-clearing for integer array cells
6
7  new Foo fooObject
8  fooArray[0] <=> fooObject  // Legal object array cell assignment
9  new Foo fooArray[2]      // Legal object array cell assignment
10
11 ...                       // Clear all array cells
12
13 delete Foo fooArray[0]    // Legal object array cell zero-clearing
14 delete Foo fooArray[1]    // Legal object array cell zero-clearing

```

Listing 2.1: Assignment of array elements

As with ROOPL++ objects instantiated outside of **construct**/**destruct** blocks, arrays must be deleted before program termination to reversibly allow the system to reclaim the memory. Before deletion of an array, all its elements must be zero-cleared such that no garbage data resides in memory after erasure of the array reference.

Consider the statement

$$\mathbf{delete\ int}[e]\ x$$

with the following mechanics

1. The reference x may be modified by swapping, assigning cell element values and zero-clearing cell element values, but must be restored to an array of same type with fully zero-cleared cells before the **delete** statement. Otherwise, the meaning of the statement is undefined.
2. The value of the expression e is evaluated and used to reclaim the allocated memory space.
3. If the reference x is a fully zero-cleared array upon the **delete** statement execution, the zero-cleared memory is reclaimed by the system.

With reversible, fixed-sized arrays of varying types, we must be extremely careful when updating and assigning values, to ensure we maintain reversibility and avoid irreversible statements. Therefore, when assigning or updating integer elements with one of the reversible assignment operators, we prohibit the cell value from being reference on the right hand side, meaning the following statement is prohibited

$$x[5] += x[5] + 1$$

However, we do allow other initialized, non-zero-cleared array elements from the same array or arrays of same type to be referenced in the right hand side of the statement. As with regular assignment, we still prohibit the left side reference to occur in the right side, meaning the following statements are also prohibited

$$\begin{aligned}
 x &+= y[x] \\
 y[x] &+= x
 \end{aligned}$$

2.5 Referencing

Besides the addition of dynamically lifetimed objects and arrays, ROOPL++ also increases program flexibility by allowing multiple references to objects and arrays through the usage of the **copy** statement. Once instantiated through either a **new** or **construct/destruct** block, an object or array reference can be copied into another zero-cleared variable. The reference acts as a regular instance and can be modified through methods as per usual. To delete a reference, the logical inverse statement **uncopy** must be used.

The syntax for referencing consists of the statement

$$\mathbf{copy} \ c \ x \ x'$$

which copies a reference of variable x , an instance of class or array c , and stores the reference in variable x' .

For deleting copies, the following statement is used

$$\mathbf{uncopy} \ c \ x \ x'$$

which simply zero-clears variable x' , which is a reference to variable x , an instance of class or array c .

The mechanism of the **copy** statement is simply as follows

1. The memory address stored in variable x is copied into the zero-cleared variable x' . If x' is not zero-cleared or x is not a class instance, then **copy** is undefined.

The mechanism of the **uncopy** statement is simply as follows

1. The memory address stored in variable x' is zero-cleared if it matches the address stored in x . If x' is not a copy of x or x has been zero-cleared before the **uncopy** statement is executed, said statement is undefined.

As references do not require all fields or cells to be zero-cleared (as they are simple pointers to existing objects or arrays), the reversible programmer should carefully ensure that all references are un-copied before deleting said object or array, as copied references to cleared objects or arrays would be pointing to cleared memory, which might be used later by the system. These type of references are also known as *dangling pointers*.

It should be noted, that from a language design perspective, it is the programmer's responsibility to ensure such situations do not occur. From an implementation perspective, such situations are usually checked by the compiler either statically during compilation or during the actual runtime of the program. This is addressed later in sections 3.3 and 4.9.

2.6 Local Blocks

The local block presented in the extended JANUS in [29] consisted of a local variable allocation, a statement and a local variable deallocation. These local variable blocks add immense programmer usability as they introduce a form of reversible temporary variable. The ROOPL compiler features support for local integer blocks, but not object blocks. In ROOPL++, local blocks can be instantiated with all of the languages variable types; integers, arrays and user-defined types in the form of objects.

Local integer blocks work exactly the same as in ROOPL and JANUS, where the local variable initialized will be set to the evaluated result of a given expression.

Local array and object blocks feature a number of different options. If a local array or object block is initialized with a **nil** value, the variable must afterwards be initialized using a new statement before any type-specific functionality is accessible. If the block is initiated with an existing object or array reference, the local variable essentially becomes a reference copy, analogous to a variable initialized from a **copy** statement.

<code>construct c x s destruct x</code>	$\stackrel{\text{def}}{=}$	<code>local c x = nil new c x s delete c x delocal c x = nil</code>
--	----------------------------	--

Figure 2.3: **construct/destruct**-blocks can be considered syntactic sugar

For objects, the **construct/destruct**-blocks can be considered syntactic sugar for a local block defined with a **nil** value, containing a **new** statement in the beginning of its statement block and a **delete** statement in the very end, as shown in figure 2.3.

As local array and object blocks allow freedom in terms of their interaction with other statements in the language, it is the programmer's responsibility that the local variable is deallocated using a correct expression at the end of the block definition. The value of the variable is a pointer to an object or an array. Said object or array must have all fields/cells zero-cleared before the pointer is zero-cleared at the end of the local block. If the pointer is at any point exchanged with the pointer of another object or array using the **swap** statement, the same conditions apply.

2.7 ROOPL++ Expressiveness

By introducing dynamic lifetime objects and by allowing objects to be referenced multiple times, we can express non-trivial reversible programs. To demonstrate the capacities, expressiveness and possibilities of ROOPL++, the following section presents previously unseen reversible data structures, which now are feasible, written in ROOPL++.

2.7.1 Linked List

Haulund presented a linked list implemented in ROOPL in [11]. The implementation featured a *ListBuilder* and a *Sum* class, required to determine and retain the sum of a constructed linked list as the statically scoped object blocks of ROOPL would deallocate automatically after building the full list. In ROOPL++, we do not face the same challenges and the implementation becomes much more straightforward. Figure 2.5 implements a *LinkedList* class, which simply has the head of the list and the list length as its internal fields. For demonstration, the class allows extension of the list by either appending or prepending cell elements to the list. In either case, we first check if the *head* field is initialized. If not, the cell we are either appending or prepending simply becomes the new head of the list. If we are appending a cell the *Cell*-class *append* method is called on the *head* cell with the new cell as its only argument. When prepending, the existing head is simply appended to the new cell and the new cell is set as head of the linked list.

```
1  class Cell
2      Cell next
3      int data
4
5      method constructor(int value)
6          data ^= value
7
8      method append(Cell cell)
9          if next = nil & cell != nil then
10             next <=> cell           // Store as next cell if current cell is end of list
11          else skip
12          fi next != nil & cell = nil
13
14          if next != nil then
15             call next::append(cell) // Recursively search until we reach end of list
16          else skip
17          fi next != nil
```

Figure 2.4: Linked List cell class

Figure 2.4 shows the *Cell* class of the linked list which has a *next* and a *data* field, a constructor and the *append* method. The *append* method works by recursively looking through the linked cell nodes until we reach the end of the free list, where the *next* field has not been initialized yet. When we find such a cell, we simply swap the contents of the *next* and *cell* variables, s.t. the cell becomes the new end of the linked list.

An interesting observation is that the *append* method is called an additional time *after* setting the cell as the new end of the linked list. In a non-reversible programming language, we would simply call *append* in the *else*-branch of the first conditional. In the reversible setting, this is not an option, as the *append* call would modify the value of the *next* and *cell* variables and as

```

1  class LinkedList
2      Cell head
3      int listLength
4
5      method insertHead(Cell cell)
6          if head = nil & cell != nil then
7              head <=> cell          // Set cell as head of list if list is empty
8          else skip
9          fi head != nil & cell = nil
10
11     method appendCell(Cell cell)
12         call insertHead(cell)      // Insert as head if empty list
13
14         if head != nil then
15             call head::append(cell) // Iterate until we hit end of list
16         else skip
17         fi head != nil
18
19         listLength += 1            // Increment length
20
21     method prependCell(Cell cell)
22         call insertHead(cell)      // Insert as head if empty list
23
24         if cell != nil & head != nil then
25             call cell::append(head) // Set cell.next = head. head = nil after execution
26         else skip
27         fi cell != nil & head = nil
28
29         if cell != nil & head = nil then
30             cell <=> head          // Set head = cell. Cell is nil after execution
31         else skip
32         fi cell = nil & head != nil
33
34         listLength += 1            // Increment length
35
36     method length(int result)
37         result ^= listLength

```

Figure 2.5: Linked List class

such, corrupt the control flow as the exit condition would be true after executing both the then- and else-branch of the conditional. To avoid this, we simply call one additional time with a **nil** value *cell*. This "wasted" additional call with a **nil** value is a recurring technique in the following presented reversible data structure implementations.

2.7.2 Binary Tree

Figures 2.6, 2.8 and 2.7 shows the implementation of a binary tree in form of a rooted, unbalanced, min-heap. The *Tree* class shown in figure 2.6 has a single root node field and the three methods *insertNode*, *sum* and *mirror*. For insertion, the *insertNode* method is called from the *root*, if it is initialized and if not, the passed node parameter is simply set as the new root of the tree. The *insertNode* method implemented in the *Node* class shown in figure 2.8 first determines if we need to insert left or right but checking the passed value against the value of the current node. This is done recursively, until an uninitialized node in the correct subtree has been found. Note that as a consequence of reversibility, the value of node we wish to insert must be passed separately in the method call as we otherwise cannot zero-clear it after swapping the node we are inserting

with either the right or left child of the current cell.

```
1  class Tree
2      Node root
3
4      method insertNode(Node node, int value)
5          if root = nil & node != nil then
6              root <=> node
7          else skip
8          fi root != nil & node = nil
9
10         if root != nil then
11             call root::insertNode(node, value)
12         else skip
13         fi root != nil
14
15     method sum(int result)
16         if root != nil then
17             call root::getSum(result)
18         else skip
19         fi root != nil
20
21     method mirror()
22         if root != nil then
23             call root::mirror()
24         else skip
25         fi root != nil
```

Figure 2.6: Binary Tree class

Summing and mirroring the tree works in a similar fashion by recursively iterating each node of the tree. For summing we simply add the value of the node to the sum and for mirroring we swap the children of the node and then recursively swap the children of the left and right node, if initialized. The sum and mirror methods are implemented in figure 2.7.

```
1  method getSum(int result)
2      result += value                                // Add the value of this node to the sum
3
4      if left != nil then
5          call left::getSum(result)                  // If we have a left child, follow that path
6      else skip                                       // Else, skip
7      fi left != nil
8
9      if right != nil then
10         call right::getSum(result)                  // If we have a right child, follow that path
11     else skip                                       // Else, skip
12     fi right != nil
13
14     method mirror()
15         left <=> right                                // Swap left and right children
16
17         if left = nil then skip
18         else call left::mirror()                    // Recursively swap children if left != nil
19         fi left = nil
20
21         if right = nil then skip
22         else call right::mirror()                   // Recursively swap children if right != nil
23         fi right = nil
```

Figure 2.7: Binary Tree node class (cont)

```

1  class Node
2      Node left
3      Node right
4      int value
5
6  method setValue(int newValue)
7      value ^= newValue
8
9  method insertNode(Node node, int nodeValue)
10     // Determine if we insert left or right
11     if nodeValue < value then
12         if left = nil & node != nil then
13             // If open left node, store here
14             left <=> node
15         else skip
16         fi left != nil & node = nil
17
18         if left != nil then
19             // If current node has left, continue iterating
20             call left::insertNode(node, nodeValue)
21         else skip
22         fi left != nil
23     else
24         if right = nil & node != nil then
25             // If open right node spot, store here
26             right <=> node
27         else skip
28         fi right != nil & node = nil
29
30         if right != nil then
31             // If current node has, continue searching
32             call right::insertNode(node, nodeValue)
33         else skip
34         fi right != nil
35     fi nodeValue < value

```

Figure 2.8: Binary Tree node class

2.7.3 Doubly Linked List

Finally, we present the reversible doubly linked list, shown in figures 2.10-2.12. A *cell* in a doubly linked list contains a reference to itself named *self*, a reference to its left and right neighbours, a data and an index field. As with the linked list and binary tree implementation the *DoubleLinkedList* class has a field referencing the head of the list and its *appendCell* method is identical to the one of the linked list.

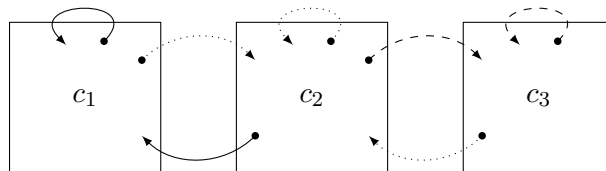


Figure 2.9: Multiple identical reference are needed for a doubly linked list implementation

This data structure is particularly interesting, as it, unlike the former two presented structures, cannot be expressed in ROOPL, as this requires multiple reference to objects, in order for an object to point to itself and to its left and right neighbours. Figure 2.9 shows the multiple

references needed for the doubly linked list implementation denoted by the three different arrow types.

```

1  class DoublyLinkedList
2      Cell head
3      int length
4
5      method appendCell(Cell cell)
6          if head = nil & cell != nil then
7              head <=> cell
8          else skip
9          fi head != nil & cell = nil
10
11         if head != nil then
12             call head::append(cell)
13         else skip
14         fi head != nil
15
16         length += 1

```

Figure 2.10: Doubly Linked List class

When we append a cell to the list, we first search recursively through the list until we are at the end. The new cell is then set as *right* of the current cell. A reference to the current self is created using the **copy** statement, and set as *left* of the new end of the list, thus resulting in the new cell being linked to list and now acting as end of the list.

```

1  class Cell
2      int data
3      int index
4      Cell left
5      Cell right
6      Cell self
7
8      method setData(int value)
9          data ^= value
10
11      method setIndex(int i)
12          index ^= i
13
14      method setLeft(Cell cell)
15          left <=> cell
16
17      method setRight(Cell cell)
18          right <=> cell
19
20      method setSelf(Cell cell)
21          self <=> cell

```

Figure 2.11: Doubly Linked List Cell class

The data structure could relatively easily be extended to work as a dynamic array. Currently each cell contains an *index* field, specifying their position in the list. If, say, we wanted to insert some new data at index n , without updating the existing value, but essentially squeezing in a new cell, we could add a method to the *DoublyLinkedList* class taking a data value and an index. When executing this method, we could iterate the list until we reach the cell with index n , construct a new *cell* instance, update required *left* and *right* pointers to insert the new cell at

```

1  method append(Cell cell)
2      if right = nil & cell != nil then      // If current cell does not have a right neighbour
3          right <=> cell                        // Set new cell as right neighbour of current cell
4
5          local Cell selfCopy = nil
6          copy Cell self selfCopy              // Copy reference to current cell
7          call right::setLeft(selfCopy)        // Set current as left of right neighbour
8          delocal Cell selfCopy = nil
9
10         local int cellIndex = index + 1
11         call right::setIndex(cellIndex) // Set index in right neighbour of current
12         delocal int cellIndex = index + 1
13     else skip
14     fi right != nil & cell = nil
15
16     if right != nil then
17         call right::append(cell)            // Keep searching for empty right neighbour
18     else skip
19     fi right != nil

```

Figure 2.12: Doubly Linked List Cell class (cont)

the correct position, in such a way that the old cell at index n now is the new right neighbour of the cell and finally recursively iterating the list, incrementing the index of cells to the right of the new cell by one. In reverse, this would remove a cell from the list. If we want to update an existing value at a index, a similar technique could be used, where we iterate through the cells until we find the correct index. If we are given an index that is out of bounds in terms of the current length of the list, we could extend the tail on the list until reach a cell with the wanted index. When we are zero-clearing a value that is the furthest index, the inverse would apply, and as such we would zero-clear the cell, and the deallocate cells until we reach a cell which does not have a zero-cleared *data* field.

This extended doubly linked list would also allow lists of n -dimensional lists, as the type of the *data* field simply could be changed to, say, a *FooDoublyLinkedList*, resulting in an array of Foo arrays.

2.8 Type System

The type system of ROOPL++ expands on the type system of ROOPL presented by Haulund [11] and is analogously described by syntax-directed inference typing rules in the style of Winskel [28]. As ROOPL++ introduces two new types in form of *references* and arrays, a few ROOPL typing rules must be modified to accommodate these added types. For completeness all typing rules, including unmodified rules, are included in the following sections.

2.8.1 Preliminaries

The types in ROOPL++ are given by the following grammar:

$$\tau ::= \mathbf{int} \mid c \in \text{ClassIDs} \mid r \in \text{ReferenceIDs} \mid i \in \text{IntegerArrayIDs} \mid o \in \text{ClassArrayIDs}$$

The type environment Π is a finite map pairing variables to types, which can be applied to an identifier x using the $\Pi(x)$ notation. Notation $\Pi' = \Pi[x \mapsto \tau]$ defines updates and creation of a new type environment Π' such that $\Pi'(x) = \tau$ and $\Pi'(y) = \Pi(y)$ if $x \neq y$, for some variable identifier x and y . The empty type environment is denoted as $[]$ and the function $\text{vars} : \text{Expressions} \rightarrow \text{VarIDs}$ is described by the following definition

$$\begin{aligned} \text{vars}(\bar{n}) &= \emptyset \\ \text{vars}(\mathbf{nil}) &= \emptyset \\ \text{vars}(x) &= \{ x \} \\ \text{vars}(x[e]) &= \{ x \} \cup \text{vars}(e) \\ \text{vars}(e_1 \otimes e_2) &= \text{vars}(e_1) \cup \text{vars}(e_2). \end{aligned}$$

The binary subtype relation $c_1 \prec: c_2$ is required for supporting subtype polymorphism and is defined as follows:

$$\begin{aligned} c_1 \prec: c_2 & \quad \text{if } c_1 \text{ inherits from } c_2 \\ c \prec: c & \quad (\textit{reflexivity}) \\ c_1 \prec: c_3 & \quad \text{if } c_1 \prec: c_2 \text{ and } c_2 \prec: c_3 \text{ } (\textit{transitivity}) \end{aligned}$$

Furthermore, we formally define object models in such a way that inherited fields and methods are included, unless overridden by the derived fields. Therefore, we define Γ to be the class map of a program p , such that Γ is a finite map from class identifiers to tuples of methods and fields for the class p . Application of a class map Γ to some class cl is denoted as $\Gamma(cl)$. Construction of a class map is done through function *gen*, as shown in figure 2.13. Figure 2.14 defines the *fields* and *methods* functions to determine these given a class. Set operation \oplus defines method overloading by dropping base class methods if a similarly named method exists in the derived class. The definitions shown in Figure 2.13 and 2.14 are originally from [11].

$$\text{gen}\left(\overbrace{cl_1, \dots, cl_n}^p\right) = \overbrace{\left[\alpha(cl_1) \mapsto \beta(cl_1), \dots, \alpha(cl_n) \mapsto \beta(cl_n)\right]}^\Gamma$$

$$\alpha(\text{class } c \dots) = c \quad \beta(cl) = (\text{fields}(cl), \text{methods}(cl))$$

Figure 2.13: Definition *gen* for constructing the finite class map Γ of a given program p , originally from [11]

$$\text{fields}(cl) = \begin{cases} \eta(cl) & \text{if } cl \sim [\text{class } c \dots] \\ \eta(cl) \cup \text{fields}(\alpha^{-1}(c')) & \text{if } cl \sim [\text{class } c \text{ inherits } c' \dots] \end{cases}$$

$$\text{methods}(cl) = \begin{cases} \delta(cl) & \text{if } cl \sim [\text{class } c \dots] \\ \delta(cl) \uplus \text{methods}(\alpha^{-1}(c')) & \text{if } cl \sim [\text{class } c \text{ inherits } c' \dots] \end{cases}$$

$$A \uplus B \stackrel{\text{def}}{=} A \cup \left\{ m \in B \mid \nexists m' \left(\zeta(m') = \zeta(m) \wedge m' \in A \right) \right\}$$

$$\zeta(\text{method } q (\dots) s) = q \quad \eta(\text{class } c \dots \overbrace{t_1 f_1 \dots t_n f_n}^{fs} \dots) = fs$$

$$\delta(\text{class } c \dots \overbrace{\text{method } q_1 (\dots) s_1 \dots \text{method } q_n (\dots) s_n}^{ms} \dots) = ms$$

Figure 2.14: Definition of fields and methods, originally from [11]

Finally, we formally define a link between arrays of a given type and other types. The function *arrayType*, defined in figure 2.15, is c if the passed array a is an array of class c instances.

$$\text{arrayType}(a) = \begin{cases} c & \text{if } a \in \text{ClassArrayIDs} \text{ and } a \text{ is a } c \text{ array} \\ \text{int} & \text{if } a \in i \end{cases}$$

Figure 2.15: Definition *arrayType* for mapping types of arrays to either class types or the integer type

2.8.2 Expressions

The type judgment

$$\overline{\Pi \vdash_{expr} e : \tau}$$

defines the type of expressions. The judgment reads as: under type environment Π , expression e has type τ .

$$\begin{array}{c} \overline{\Pi \vdash_{expr} n : \mathbf{int}} \text{ T-CON} \quad \frac{\Pi(x) = \tau}{\Pi \vdash_{expr} x : \tau} \text{ T-VAR} \quad \frac{\tau \neq \mathbf{int}}{\Pi \vdash_{expr} \mathbf{nil} : \tau} \text{ T-NIL} \\[10pt] \frac{\Pi \vdash_{expr} e_1 : \mathbf{int} \quad \Pi \vdash_{expr} e_2 : \mathbf{int}}{\Pi \vdash_{expr} e_1 \otimes e_2 : \mathbf{int}} \text{ T-BINOPINT} \\[10pt] \frac{\Pi \vdash_{expr} e_1 : c \quad \Pi \vdash_{expr} e_2 : c \quad \otimes \in \{=, !=\}}{\Pi \vdash_{expr} e_1 \otimes e_2 : \mathbf{int}} \text{ T-BINOPOBJ} \end{array}$$

Figure 2.16: Typing rules for expressions in ROOPL, originally from [11]

The original expression typing rules from ROOPL are shown in figure 2.16. The type rules T-CON, T-VAR and T-NIL defines typing of the simplest expressions. Numeric literals are of type **int**, typing of variable expressions depends on the type of the variable in the type environment and the **nil** literal is a non-integer type. All binary operations are defined for integers, while only equality-operators are defined for objects.

With the addition of the ROOPL++ array type, we extend the expression typing rules with rule T-ARRELEMPVAR which defines typing for array element variables, shown in figure 2.17.

$$\frac{\Pi(x) = \tau[\] \quad \Pi_{expr} \vdash e : \mathbf{int}}{\Pi \vdash_{expr} x[e] : \tau} \text{ T-ARRELEMPVAR}$$

Figure 2.17: Typing rule extension for the ROOPL typing rules

2.8.3 Statements

The type judgment

$$\overline{\langle \Pi, c \rangle \vdash_{stmt}^{\Gamma} s}$$

defines well-typed statements. The judgment reads as under type environment Π within class c , statement s is well-typed with class map Γ .

$$\begin{array}{c}
\frac{x \notin \text{vars}(e) \quad \Pi \vdash_{\text{expr}} e : \mathbf{int} \quad \Pi(x) = \mathbf{int}}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} x \odot = e} \text{T-ASSVAR} \\[10pt]
\frac{\Pi \vdash_{\text{expr}} e_1 : \mathbf{int} \quad \langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} s_1 \quad \langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} s_2 \quad \Pi \vdash_{\text{expr}} e_2 : \mathbf{int}}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} \mathbf{if } e_1 \mathbf{ then } s_1 \mathbf{ else } s_2 \mathbf{ fi } e_2} \text{T-IF} \\[10pt]
\frac{\Pi \vdash_{\text{expr}} e_1 : \mathbf{int} \quad \langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} s_1 \quad \langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} s_2 \quad \Pi \vdash_{\text{expr}} e_2 : \mathbf{int}}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} \mathbf{from } e_1 \mathbf{ do } s_1 \mathbf{ loop } s_2 \mathbf{ until } e_2} \text{T-LOOP} \\[10pt]
\frac{\langle \Pi[x \mapsto c'], c \rangle \vdash_{\text{stmt}}^{\Gamma} s}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} \mathbf{construct } c' x s \mathbf{ destruct } x} \text{T-OBJBLOCK} \quad \frac{}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} \mathbf{skip}} \text{T-SKIP} \\[10pt]
\frac{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} s_1 \quad \langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} s_2}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} s_1 s_2} \text{T-SEQ} \quad \frac{\Pi(x_1) = \Pi(x_2)}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} x_1 \Leftrightarrow x_2} \text{T-SWPVAR} \\[10pt]
\frac{\Gamma(\Pi(c)) = (fields, methods) \quad \left(\mathbf{method } q(t_1 y_1, \dots, t_n y_n) s \right) \in methods \quad \{x_1, \dots, x_n\} \cap fields = \emptyset \quad i \neq j \implies x_i \neq x_j \quad \Pi(x_1) \prec t_1 \dots \Pi(x_n) \prec t_n}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} \mathbf{call } q(x_1, \dots, x_n)} \text{T-CALL} \\[10pt]
\frac{\Gamma(\Pi(x_0)) = (fields, methods) \quad \left(\mathbf{method } q(t_1 y_1, \dots, t_n y_n) s \right) \in methods \quad i \neq j \implies x_i \neq x_j \quad \Pi(x_1) \prec t_1 \dots \Pi(x_n) \prec t_n}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} \mathbf{call } x_0 :: q(x_1, \dots, x_n)} \text{T-CALLO} \\[10pt]
\frac{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} \mathbf{call } q(x_1, \dots, x_n)}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} \mathbf{uncall } q(x_1, \dots, x_n)} \text{T-UC} \quad \frac{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} \mathbf{call } x_0 :: q(x_1, \dots, x_n)}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} \mathbf{uncall } x_0 :: q(x_1, \dots, x_n)} \text{T-UCO}
\end{array}$$

Figure 2.18: Typing rules for statements in ROOPL, originally from [11]

Typing rule T-ASSVAR defines variable assignments for an integer variable and an integer expression result, given that the variable x does not occur in the expression e .

The type rules T-IF and T-LOOP defines reversible conditionals and loops as known from JANUS, where entry and exit conditions are integers and branch and loop statements are well-typed statements.

The object block, introduced in ROOPL, is only well-typed if its body statement is well-typed.

The **skip** statement is always well-typed, while a sequence of statements are well-typed if each of the provided statements are. Variable **swap** statements are well-typed if both operands are of the same type under type environment Π .

As with ROOPL, type correctness of local method invocation is defined in rule T-CALL iff:

- The number of arguments matches the method arity
- No class fields are present in the arguments passed to the method (To prevent irreversible updates)
- The argument list contains unique elements
- Each argument is a subtype of the type of the equivalent formal parameter.

For foreign method invocations, typing rule T-CALLO. A foreign method invocation is well-typed using the same rules as for T-CALL besides having no restrictions on class fields parameters in the arguments, but an added rule stating that the callee object x_0 must not be passed as an argument.

The typing rules T-UC and T-UCO defines uncalls of methods in terms of their respective inverse counterparts.

$$\begin{array}{c}
\frac{\Pi(x) = \mathbf{int}[] \quad \Pi \vdash_{expr} e_1 : \mathbf{int} \quad \frac{\left(x \cup \text{vars}(e_1) \right) \cap \text{vars}(e_2) = \emptyset \quad \Pi \vdash_{expr} e_2 : \mathbf{int}}{\langle \Pi, c \rangle \vdash_{stmt}^{\Gamma} x[e_1] \odot = e_2} \text{T-ARRELEMASS}} \\
\\
\frac{\Pi(x) = c'}{\langle \Pi, c \rangle \vdash_{stmt}^{\Gamma} \mathbf{new} \ c' \ x} \text{T-OBJNEW} \quad \frac{\Pi(x) = c'}{\langle \Pi, c \rangle \vdash_{stmt}^{\Gamma} \mathbf{delete} \ c' \ x} \text{T-OBJDLT} \\
\\
\frac{\text{arrayType}(a) \in \{ \text{classIDs}, \mathbf{int} \} \quad \Pi \vdash_{expr} e = \mathbf{int} \quad \Pi(x) = a[]}{\langle \Pi, c \rangle \vdash_{stmt}^{\Gamma} \mathbf{new} \ a[e] \ x} \text{T-ARRNEW} \\
\\
\frac{\text{arrayType}(a) \in \{ \text{classIDs}, \mathbf{int} \} \quad \Pi \vdash_{expr} e = \mathbf{int} \quad \Pi(x) = a[]}{\langle \Pi, c \rangle \vdash_{stmt}^{\Gamma} \mathbf{delete} \ a[e] \ x} \text{T-ARRDLT} \\
\\
\frac{\Pi(x) = c' \quad \Pi(x') = c'}{\langle \Pi, c \rangle \vdash_{stmt}^{\Gamma} \mathbf{copy} \ c' \ x \ x'} \text{T-CP} \quad \frac{\Pi(x) = c' \quad \Pi(x') = c'}{\langle \Pi, c \rangle \vdash_{stmt}^{\Gamma} \mathbf{uncopy} \ c' \ x \ x'} \text{T-UCP} \\
\\
\frac{\langle \Pi, c \rangle \vdash_{expr} e_1 : c' \quad \langle \Pi[x \mapsto c'], c \rangle \vdash_{stmt}^{\Gamma} s \quad \langle \Pi, c \rangle \vdash_{expr} e_2 : c'}{\langle \Pi, c \rangle \vdash_{stmt}^{\Gamma} \mathbf{local} \ c' \ x = e_1 \ s \ \mathbf{delocal} \ c' \ x = e_2} \text{T-LOCALBLOCK}
\end{array}$$

Figure 2.19: Typing rules extensions for statements in ROOPL++

Figure 2.19 shows the typing rules for the extensions made to ROOPL in ROOPL++, covering the **new/delete** and **copy/uncopy** statements for objects and arrays and local blocks.

The typing rule T-ARRELEMASS defines assignment to integer array element variables, and is well-typed when the type of array x is **int**, the variable $x[e_1]$ is not present in the right-hand

side of the statement, no variables in e_1 exist in e_2 and both expressions e_1 and e_2 evaluates to integers.

The T-OBJNEW and T-OBJDLT rules define well-typed **new** and **delete** statements for dynamically lifetimed objects. The **new** statement is well-typed, as long as $c' \in \text{classIDs}$ and the variable x is of type c' under type environment Π and **delete** is also well-typed if the type of x under type environment Π is equal to c' .

The T-ARRNEW and T-ARRDLT rules define well-type **new** and **delete** statement for ROOPL++ arrays. The **new** statement is well-typed, if the type of the array either is a classID or **int**, the length expression evaluates to an integer and x is of of type $a[]$ under the type environment Π , and **delete** is well-typed if the type of the array is either a classID or **int**, the length expression evaluates to an integer and x is equal to the array type a .

Typing rules T-CP and T-UCP define well-typed reference copy and un-copying statements. A well-typed **copy** or **uncopy** statement requires that the types of x and x' both are c' under type environment Π

The rule T-LOCALBLOCK defines well-typed local blocks. A local block is well-typed if its two expression e_1 and e_2 are well-typed and its body statement s is well-typed.

2.8.4 Programs

As with ROOPL, a ROOPL++ program is well-typed if all of its classes and their respective methods are well-typed and if there exists a nullary main method. Figure 2.20 shows the typing rules for class methods, classes and programs.

$$\begin{array}{c}
\frac{\langle \Pi[x_1 \mapsto t_1, \dots, x_n \mapsto t_n], c \rangle \vdash_{stmt}^{\Gamma} s}{\langle \Pi, c \rangle \vdash_{meth}^{\Gamma} \text{method } q(t_1x_1, \dots, t_nx_n) s} \text{T-METHOD} \\
\\
\frac{\Pi = [f_1 \mapsto t_1, \dots, f_n \mapsto t_n] \quad \Gamma(c) = \left(\overbrace{\{\langle t_1, f_1 \rangle, \dots, \langle t_i, f_i \rangle\}}^{fields}, \overbrace{\{m_1, \dots, m_n\}}^{methods} \right)}{\vdash_{class}^{\Gamma} c} \text{T-CLASS} \\
\\
\frac{\Gamma = \text{gen}(c_1, \dots, c_n) \quad \vdash_{class}^{\Gamma} c_1 \quad \dots \quad \vdash_{class}^{\Gamma} c_n}{\vdash_{prog} c_1 \dots c_n} \text{T-PROG}
\end{array}$$

Figure 2.20: Typing rules for class methods, classes and programs, originally from [11]

2.9 Language Semantics

The following sections contain the operational semantics of ROOPL++, as specified by syntax-directed inference rules.

2.9.1 Preliminaries

We define l to be a location. We define a location for integer variables to bind to a single location in program memory and a vector of memory locations for object and array variables, where the vector is the size of the object or array. A memory location is in the set of non-negative integers, \mathbb{N}_0 . An environment γ is a partial function mapping variables to memory locations. A store μ is a partial function mapping memory locations to values. An object is a tuple of a class name and an environment mapping fields to memory locations. A value is either an integer, an object, a location or a vector of locations.

Applications of environments γ and stores μ are analogous to the type environment Γ , defined in section 2.8.1.

$$\begin{aligned} l \in \text{Locs} &= \mathbb{N}_0 \\ \gamma \in \text{Envs} &= \text{VarIDs} \rightarrow \text{Locs} \\ \mu \in \text{Stores} &= \text{Locs} \rightarrow \text{Values} \\ \text{Objects} &= \left\{ \langle c_f, \gamma_f \rangle \mid c_f \in \text{ClassIDs} \wedge \gamma_f \in \text{Envs} \right\} \\ v \in \text{Values} &= \mathbb{Z} \cup \text{Objects} \cup \text{Locs} \cup [\text{Locs}] \end{aligned}$$

Figure 2.21: Semantic values, originally from [11]

2.9.2 Expressions

The judgment:

$$\langle \gamma, \mu \rangle \vdash_{\text{expr}} e \Rightarrow v$$

defines the meaning of expressions. We say that under environment γ and store μ , expression e evaluates to value v .

$$\begin{array}{c} \frac{}{\langle \gamma, \mu \rangle \vdash_{\text{expr}} n \Rightarrow \bar{n}} \text{CON} \quad \frac{}{\langle \gamma, \mu \rangle \vdash_{\text{expr}} x \Rightarrow \mu(\gamma(x))} \text{VAR} \quad \frac{}{\langle \gamma, \mu \rangle \vdash_{\text{expr}} \mathbf{nil} \Rightarrow 0} \text{NIL} \\[10pt] \frac{\langle \gamma, \mu \rangle \vdash_{\text{expr}} e_1 \Rightarrow v_1 \quad \langle \gamma, \mu \rangle \vdash_{\text{expr}} e_2 \Rightarrow v_2 \quad \llbracket \otimes \rrbracket(v_1, v_2) = v}{\langle \gamma, \mu \rangle \vdash_{\text{expr}} e_1 \otimes e_2 \Rightarrow v} \text{BINOP} \end{array}$$

Figure 2.22: Semantic inference rules for expressions, originally from [11]

As shown in figure 2.22, expression evaluation has no effects on the store. Logical values are represented by *truthy* and *falsey* values of any non-zero value and zero respectively. The evaluation of binary operators is presented in figure 2.24.

$$\frac{\langle \gamma, \mu \rangle \vdash_{expr} e \Rightarrow v \quad \gamma(x) = l \quad \mu(l)[v] = l' \quad \mu(l') = w}{\langle \gamma, \mu \rangle \vdash_{expr} x[e] \Rightarrow w} \text{ARRELEM}$$

Figure 2.23: Extension to the semantic inference rules for expression in ROOPL++

For ROOPL++, we extend the expression ruleset with a single rule for array element variables shown in figure 2.23. As with the expressions inference rules in ROOPL, this extension has no effect on the store.

$\llbracket + \rrbracket(v_1, v_2)$	$= v_1 + v_2$	$\llbracket \% \rrbracket(v_1, v_2)$	$= v_1 \text{ mod } v_2$
$\llbracket - \rrbracket(v_1, v_2)$	$= v_1 - v_2$	$\llbracket \& \rrbracket(v_1, v_2)$	$= v_1 \wedge v_2 \quad , \text{bitwise}$
$\llbracket * \rrbracket(v_1, v_2)$	$= v_1 \times v_2$	$\llbracket | \rrbracket(v_1, v_2)$	$= v_1 \vee v_2 \quad , \text{bitwise}$
$\llbracket / \rrbracket(v_1, v_2)$	$= v_1 \div v_2$	$\llbracket ^ \rrbracket(v_1, v_2)$	$= v_1 \oplus v_2$
$\llbracket \&\& \rrbracket(v_1, v_2)$	$= \begin{cases} 0 & \text{if } v_1 = 0 \vee v_2 = 0 \\ 1 & \text{otherwise} \end{cases}$	$\llbracket <= \rrbracket(v_1, v_2)$	$= \begin{cases} 0 & \text{if } v_1 \leq v_2 \\ 1 & \text{otherwise} \end{cases}$
$\llbracket || \rrbracket(v_1, v_2)$	$= \begin{cases} 0 & \text{if } v_1 = v_2 = 0 \\ 1 & \text{otherwise} \end{cases}$	$\llbracket >= \rrbracket(v_1, v_2)$	$= \begin{cases} 0 & \text{if } v_1 \geq v_2 \\ 1 & \text{otherwise} \end{cases}$
$\llbracket < \rrbracket(v_1, v_2)$	$= \begin{cases} 1 & \text{if } v_1 < v_2 \\ 0 & \text{otherwise} \end{cases}$	$\llbracket = \rrbracket(v_1, v_2)$	$= \begin{cases} 0 & \text{if } v_1 = v_2 \\ 1 & \text{otherwise} \end{cases}$
$\llbracket > \rrbracket(v_1, v_2)$	$= \begin{cases} 1 & \text{if } v_1 > v_2 \\ 0 & \text{otherwise} \end{cases}$	$\llbracket != \rrbracket(v_1, v_2)$	$= \begin{cases} 0 & \text{if } v_1 \neq v_2 \\ 1 & \text{otherwise} \end{cases}$

Figure 2.24: Definition of binary expression operator evaluation, originally from [11]

2.9.3 Statements

The judgment

$$\gamma \vdash_{stmt}^{\Gamma} s : \mu \rightleftharpoons \mu'$$

defines the meaning of statements. We say that under environment γ , statement s with class map Γ reversibly transforms store μ to store μ' . Figure 2.25a, 2.25b and 2.25c defines the operational semantics of ROOPL++.

The following semantic rules have been simplified from the original ROOPL semantics [11] to better accommodate the extended language.

The inference rule SKIP defines the operational semantics of **skip** statements and has no effects on the store μ .

$$\begin{array}{c}
\frac{}{\gamma \vdash_{stmt}^{\Gamma} \text{skip} : \mu \Rightarrow \mu} \text{SKIP} \\[10pt]
\frac{\gamma \vdash_{stmt}^{\Gamma} s_1 : \mu \Rightarrow \mu' \quad \gamma \vdash_{stmt}^{\Gamma} s_2 : \mu' \Rightarrow \mu''}{\gamma \vdash_{stmt}^{\Gamma} s_1 s_2 : \mu \Rightarrow \mu''} \text{SEQ} \\[10pt]
\frac{\langle \gamma, \mu \rangle \vdash_{stmt}^{\Gamma} e \Rightarrow v \quad \llbracket \odot \rrbracket (\mu(\gamma(x)), v) = v'}{\gamma \vdash_{stmt}^{\Gamma} x \odot = e : \mu \Rightarrow \mu[\gamma(x) \mapsto v']} \text{ASSVAR} \\[10pt]
\frac{\mu(\gamma(x_1)) = v_1 \quad \mu(\gamma(x_2)) = v_2}{\gamma \vdash_{stmt}^{\Gamma} x_1 \Leftrightarrow x_2 : \mu \Rightarrow \mu[\gamma(x_1) \mapsto v_2, \gamma(x_2) \mapsto v_1]} \text{SWPVAR} \\[10pt]
\frac{\langle \gamma, \mu \rangle \vdash_{expr}^{\Gamma} e_1 \not\Rightarrow 0 \quad \gamma \vdash_{stmt}^{\Gamma} s_1 : \mu \Rightarrow \mu' \quad \gamma \vdash_{loop}^{\Gamma} (e_1, s_1, s_2, e_2) : \mu' \Rightarrow \mu''}{\gamma \vdash_{stmt}^{\Gamma} \text{from } e_1 \text{ do } s_1 \text{ loop } s_2 \text{ until } e_2 : \mu \Rightarrow \mu''} \text{LOOPMAIN} \\[10pt]
\frac{\langle \gamma, \mu \rangle \vdash_{expr}^{\Gamma} e_2 \not\Rightarrow 0}{\gamma \vdash_{loop}^{\Gamma} (e_1, s_1, s_2, e_2) : \mu \Rightarrow \mu} \text{LOOPBASE} \\[10pt]
\frac{\langle \gamma, \mu \rangle \vdash_{expr}^{\Gamma} e_2 \Rightarrow 0 \quad \gamma \vdash_{stmt}^{\Gamma} s_2 : \mu \Rightarrow \mu' \quad \langle \gamma, \mu' \rangle \vdash_{expr}^{\Gamma} e_1 \Rightarrow 0 \quad \gamma \vdash_{stmt}^{\Gamma} s_1 : \mu' \Rightarrow \mu'' \quad \gamma \vdash_{loop}^{\Gamma} (e_1, s_1, s_2, e_2) : \mu'' \Rightarrow \mu'''}{\gamma \vdash_{loop}^{\Gamma} (e_1, s_1, s_2, e_2) : \mu \Rightarrow \mu'''} \text{LOOPREC} \\[10pt]
\frac{\langle \gamma, \mu \rangle \vdash_{expr}^{\Gamma} e_1 \not\Rightarrow 0 \quad \gamma \vdash_{stmt}^{\Gamma} s_1 : \mu \Rightarrow \mu' \quad \langle \gamma, \mu' \rangle \vdash_{expr}^{\Gamma} e_2 \not\Rightarrow 0}{\gamma \vdash_{stmt}^{\Gamma} \text{if } e_1 \text{ then } s_1 \text{ else } s_2 \text{ fi } e_2 : \mu \Rightarrow \mu'} \text{IFTRUE} \\[10pt]
\frac{\langle \gamma, \mu \rangle \vdash_{expr}^{\Gamma} e_1 \Rightarrow 0 \quad \gamma \vdash_{stmt}^{\Gamma} s_1 : \mu \Rightarrow \mu' \quad \langle \gamma, \mu' \rangle \vdash_{expr}^{\Gamma} e_2 \Rightarrow 0}{\gamma \vdash_{stmt}^{\Gamma} \text{if } e_1 \text{ then } s_1 \text{ else } s_2 \text{ fi } e_2 : \mu \Rightarrow \mu'} \text{IFFALSE}
\end{array}$$

Figure 2.25a: Semantic inference rules for statements, modified from [11]

Rule SEQ defines statement sequences where the store potentially is updated between each statement execution.

Rule ASSVAR defines reversible assignment in which variable identifier x under environment γ is mapped to the value v' resulting in an updated store μ' . For variable swapping SWPVAR defines how value mappings between two variables are exchanged in the updated store.

For loops and conditionals, Rules LOOPMAIN, LOOPBASE and LOOPREC define the meaning of loop statements and IfTrue and IfFalse, similarly to the operational semantics of Janus, as

$$\begin{array}{c}
\gamma(this) = l \quad \mu(l) = l' \quad \mu(l') = \langle c, (l_1, \dots, l_m) \rangle \quad \gamma(y_i) = l'_i \\
\Gamma(c) = \left\langle \overbrace{(x_1, \dots, x_m)}^{fields}, \overbrace{(\dots, \mathbf{method} \ q(t_1 z_1, \dots, t_l z_k) \ s, \dots)}^{methods} \right\rangle \\
\frac{\gamma' = [this \mapsto l, x_1 \mapsto l_1, \dots, l_m \mapsto v_m, z_1 \mapsto l'_1, \dots, z_k \mapsto l'_k] \quad \gamma' \vdash_{stmt}^\Gamma s : \mu \Rightarrow \mu'}{\gamma \vdash_{stmt}^\Gamma \mathbf{call} \ q(y_1, \dots, y_n) : \mu \Rightarrow \mu'} \text{CALL} \\
\\
\frac{\gamma \vdash_{stmt}^\Gamma \mathbf{call} \ q(y_1, \dots, y_n) : \mu' \Rightarrow \mu}{\gamma \vdash_{stmt}^\Gamma \mathbf{uncall} \ q(y_1, \dots, y_n) : \mu \Rightarrow \mu'} \text{UNCALL} \\
\\
\gamma(x_0) = l \quad \mu(l) = l' \quad \mu(l') = \langle c, (l_1, \dots, l_m) \rangle \quad \gamma(y_i) = l'_i \\
\Gamma(c) = \left\langle \overbrace{(x_1, \dots, x_m)}^{fields}, \overbrace{(\dots, \mathbf{method} \ q(t_1 z_1, \dots, t_l z_k) \ s, \dots)}^{methods} \right\rangle \\
\frac{\gamma' = [this \mapsto l, x_1 \mapsto l_1, \dots, l_m \mapsto v_m, z_1 \mapsto l'_1, \dots, z_k \mapsto l'_k] \quad \gamma' \vdash_{stmt}^\Gamma s : \mu \Rightarrow \mu'}{\gamma \vdash_{stmt}^\Gamma \mathbf{call} \ x_0 :: q(y_1, \dots, y_n) : \mu \Rightarrow \mu'} \text{CALLOBJ} \\
\\
\frac{\gamma \vdash_{stmt}^\Gamma \mathbf{call} \ x_0 :: q(y_1, \dots, y_n) : \mu' \Rightarrow \mu}{\gamma \vdash_{stmt}^\Gamma \mathbf{uncall} \ x_0 :: q(y_1, \dots, y_n) : \mu \Rightarrow \mu'} \text{OBJUNCALL} \\
\\
\Gamma(c) = \left\langle \overbrace{(x_1, \dots, x_m)}^{fields}, methods \right\rangle \quad \gamma' = \gamma[x \mapsto l_0] \quad l_0 \notin \text{dom}(\mu) \dots l_m \notin \text{dom}(\mu) \\
\mu' = \mu \left[\gamma'(x) \mapsto l_0, l_0 \mapsto \langle c, (l_1, \dots, l_m) \rangle, l_1 \mapsto 0, \dots, l_m \mapsto 0 \right] \quad \gamma' \vdash_{stmt}^\Gamma s : \mu' \Rightarrow \mu'' \\
\mu'' = \mu''' \left[\gamma'(x) \mapsto l_0, l_0 \mapsto \langle c, (l_1, \dots, l_m) \rangle, l_1 \mapsto 0, \dots, l_m \mapsto 0 \right] \\
\frac{\gamma \vdash_{stmt}^\Gamma \mathbf{construct} \ c \ x \quad s \quad \mathbf{destruct} \ x : \mu \Rightarrow \mu'''}{\gamma \vdash_{stmt}^\Gamma \mathbf{construct} \ c \ x \quad s \quad \mathbf{destruct} \ x : \mu \Rightarrow \mu'''} \text{OBJBLOCK}
\end{array}$$

Figure 2.25b: Semantic inference rules for statements, modified from [11] (cont)

presented in [29]. LOOPMAIN is entered if e_1 is true and each iteration enters LOOPREC until e_2 is false, in which case LOOPBASE is executed. Similarly, if e_1 and e_2 are true, rule IFTRUE is entered, executing the then-branch of the conditional. If e_1 and e_2 are false, the IFFALSE rule is executed and the else-branch is executed.

Rules CALL, UNCALL, CALLOBJ and UNCALLOBJ respectively define local and non-local method invocations. For local methods, method q in current class c should be of arity n matching the number of arguments. The updated store μ' is obtained after statement body execution in the object environment. As local uncalling is the inverse of local calling, the direction of execution is simply reversed, and as such the input store a **call** statement serves as the output store of the

$$\begin{array}{c}
\frac{\langle \gamma, \mu \rangle \vdash_{stmt}^{\Gamma} e_1 \Rightarrow v_1 \quad \langle \gamma, \mu \rangle \vdash_{stmt}^{\Gamma} e_2 \Rightarrow v_2}{\gamma \vdash_{stmt}^{\Gamma} x[e_1] \odot = e_2 : \mu \Leftarrow \mu[l' \mapsto w']} \text{ASSARRELEMVAR} \\
\\
\frac{\Gamma(c) = \left\langle \overbrace{(x_1, \dots, x_m)}^{fields}, methods \right\rangle \quad \gamma(x) = l \quad l_0 \notin \text{dom}(\mu) \dots l_m \notin \text{dom}(\mu)}{\gamma \vdash_{stmt}^{\Gamma} \mathbf{new} \ c \ x : \mu[l \mapsto 0] \Leftarrow \mu \left[l \mapsto l_0, l_0 \mapsto \left\langle c, (l_1, \dots, l_m) \right\rangle, l_1 \mapsto 0, \dots, l_m \mapsto 0 \right]} \text{OBJNEW} \\
\\
\frac{\langle l, \gamma \rangle \vdash_{stmt}^{\Gamma} \mathbf{new} \ c \ x : \mu' \Leftarrow \mu}{\gamma \vdash_{stmt}^{\Gamma} \mathbf{delete} \ c \ x : \mu \Leftarrow \mu'} \text{OBJDELETE} \\
\\
\frac{\langle \gamma, \mu \rangle \vdash_{stmt}^{\Gamma} e \Rightarrow n \quad \gamma(x) = l \quad \mu(l) = 0 \quad l' \notin \text{dom}(\mu)}{\gamma \vdash_{stmt}^{\Gamma} \mathbf{new} \ a[e] \ x : \mu \Leftarrow \mu[l \mapsto l', l' \mapsto 0^n]} \text{ARRNEW} \\
\\
\frac{\langle l, \gamma \rangle \vdash_{stmt}^{\Gamma} \mathbf{new} \ a[e] \ x : \mu' \Leftarrow \mu}{\gamma \vdash_{stmt}^{\Gamma} \mathbf{delete} \ a[e] \ x : \mu \Leftarrow \mu'} \text{ARRDELETE} \\
\\
\frac{\gamma \vdash_{stmt}^{\Gamma} \mathbf{delete} \ a[e] \ x : \mu \Leftarrow \mu' \quad \gamma(x) = l \quad \gamma(x') = l' \quad \mu(l) = v}{\gamma \vdash_{stmt}^{\Gamma} \mathbf{copy} \ c \ x \ x' : \mu[l' \mapsto 0] \Leftarrow \mu[l' \mapsto v]} \text{COPY} \\
\\
\frac{\langle l, \gamma \rangle \vdash_{stmt}^{\Gamma} \mathbf{copy} \ c \ x \ x' : \mu' \Leftarrow \mu}{\gamma \vdash_{stmt}^{\Gamma} \mathbf{uncopy} \ c \ x \ x' : \mu \Leftarrow \mu'} \text{UNCOPY} \\
\\
\frac{\langle \gamma, \mu \rangle \vdash_{stmt}^{\Gamma} e_1 \Rightarrow v_1 \quad \langle \gamma, \mu' \rangle \vdash_{stmt}^{\Gamma} e_2 \Rightarrow v_2}{\frac{r \notin \text{dom}(\mu) \quad \gamma[x \mapsto r] \vdash_{stmt}^{\Gamma} s : \mu[r \mapsto v_1] \Leftarrow \mu'[r \mapsto v_2]}{\gamma \vdash_{stmt}^{\Gamma} \mathbf{local} \ c \ x = e_1 \quad s \quad \mathbf{delocal} \ x = e_2 : \mu \Leftarrow \mu'}} \text{LOCALBLOCK}
\end{array}$$

Figure 2.25c: Extension to the semantic inference rules for statements in ROOPL++

uncall statement, similarly to techniques presented in [31, 29].

The statically scoped object blocks are defined in rule OBJBLOCK. The operation semantics of these blocks are similar to **local**-blocks from JANUS. We add the reference x to a new environment and afterwards map the location of x to the object tuple at location l_0 , containing the locations of all object fields, all of which, along with l_0 , must be unused in μ . The result store μ'' is obtained after executing the body statement s in store μ' mapping x to object reference at l_0 , as long as all object fields are zero-cleared in μ''' afterwards. If any of these conditions fail, the object block statement is undefined.

Figure 2.25c shows the extensions to the semantics of ROOPL with rules for **new/delete** and

copy/uncopy statements, array element assignment and local blocks.

Rule **ASSARRELEMPVAR** defines reversible assignment to array elements. After evaluating expressions e_1 to v_1 and e_2 to v_2 , the value at the location of variable $x[v_1]$ under environment γ is mapped to the value v_3 resulting in an updated store μ' .

Dynamic object construction and destruction is defined by rules **OBJNEW** and **OBJDELETE**. For construction, x must be bound to a location l . We then make location l point to a new pair consisting of the class name and a vector of m new locations mapping object fields to locations. For destruction, x is still bound to l return l to a null pointer. As with object blocks, it is the program itself responsible for zero-clearing object fields before destruction. If the object fields are not zero-cleared, the **OBJDELETE** statement is undefined.

Array construction and destruction is very similar to object construction and destruction. The major difference is we bind the location to a vector of size equal to the evaluated expression result. For deletion, we return the location of x to a null pointer and remove the binding to the vector from the store.

Object and array referencing is defined by rules **COPY** and **UNCOPY**. A reference is created and a new store μ' obtained by mapping x' to the reference r which x current maps to, if c matches the tuple mapped to the location l . A reference is removed and a new store μ' obtained if x and x' maps to the same reference r and x' then is removed from the store.

Local blocks are as previously mentioned, semantically similar to object blocks, where the memory location of variable x is mapped to an unused reference r in the store μ . Before body statement execution, we let r bind to the evaluated value of e_1 , v_1 . The result store after body statement execution, μ' must have r mapped to the expression value of e_2 , v_2 . r is then zero-cleared using the value of expression evaluation and becomes unused again.

2.9.4 Programs

The judgment

$$\vdash_{prog} p \Rightarrow \sigma$$

defines the meaning of programs. The class p containing the main method is instantiated and the main function is executed with the partial function σ as the result, mapping variable identifiers to values, correlating to the class fields of the main class.

$$\frac{\begin{array}{l} \Gamma = \text{gen}(c_1, \dots, c_n) \quad \Gamma(c_1) = \left(\overbrace{\{\langle t_1, f_1 \rangle, \dots, \langle t_n, f_n \rangle\}}^{fields}, methods \right) \\ \left(\text{method main } () s \right) \in methods \quad \gamma = [f_1 \mapsto 1, \dots, f_i \mapsto i] \\ \mu = [1 \mapsto 0, \dots, i \mapsto 0, this \mapsto i+1, i+1 \mapsto \langle c_1, \gamma \rangle] \quad \gamma \vdash_{stmt}^{\Gamma} s : \mu \Rightarrow \mu' \end{array}}{\vdash_{prog} c_1 \dots c_n \Rightarrow (\gamma, \mu')} \text{MAIN}$$

Figure 2.26: Semantic inference rules for programs, originally from [11]

As with ROOPL programs, the fields of the main method in the main class c are bound in a new environment, starting at memory address 1, as 0 is reserved for **nil**. The fields are zero-initialized

in the new store μ and address $i + 1$ which maps to the new instance of c . After body execution, store μ' is obtained.

2.10 Program Inversion

In order to truly show that ROOPL++ in fact is a reversible language, we must demonstrate and prove local inversion of statements is possible, such that any program written in ROOPL++, regardless of context, can be executed in reverse. Haulund presented a statement inverter for ROOPL in [11], which maps statements to their inverse counterparts. Figure 2.27 shows the statement inverter, extended with the new ROOPL++ statements for construction/destruction and referencing copying/copy removal.

$\mathcal{I}[\text{skip}] = \text{skip}$	$\mathcal{I}[s_1 \ s_2] = \mathcal{I}[s_2] \ \mathcal{I}[s_1]$
$\mathcal{I}[x \ += \ e] = x \ -= \ e$	$\mathcal{I}[x \ -= \ e] = x \ += \ e$
$\mathcal{I}[x \ \wedge= \ e] = x \ \wedge= \ e$	$\mathcal{I}[x \ \<=> \ e] = x \ \<=> \ e$
$\mathcal{I}[x[e_1] \ += \ e_2] = x[e_1] \ -= \ e_2$	$\mathcal{I}[x[e_1] \ -= \ e_2] = x[e_1] \ += \ e_2$
$\mathcal{I}[x[e_1] \ \wedge= \ e_2] = x[e_1] \ \wedge= \ e_2$	$\mathcal{I}[x[e_1] \ \<=> \ e_2] = x[e_1] \ \<=> \ e_2$
$\mathcal{I}[\text{new } c \ x] = \text{delete } c \ x$	$\mathcal{I}[\text{copy } c \ x \ x'] = \text{uncopy } c \ x \ x'$
$\mathcal{I}[\text{delete } c \ x] = \text{new } c \ x$	$\mathcal{I}[\text{uncopy } c \ x \ x'] = \text{copy } c \ x \ x'$
$\mathcal{I}[\text{call } q(\dots)] = \text{uncall } q(\dots)$	$\mathcal{I}[\text{call } x :: q(\dots)] = \text{uncall } x :: q(\dots)$
$\mathcal{I}[\text{uncall } q(\dots)] = \text{call } q(\dots)$	$\mathcal{I}[\text{uncall } x :: q(\dots)] = \text{call } x :: q(\dots)$
$\mathcal{I}[\text{if } e_1 \text{ then } s_1 \text{ else } s_2 \text{ fi } e_2]$	$= \text{if } e_1 \text{ then } \mathcal{I}[s_1] \text{ else } \mathcal{I}[s_2] \text{ fi } e_2$
$\mathcal{I}[\text{from } e_1 \text{ do } s_1 \text{ loop } s_2 \text{ until } e_2]$	$= \text{from } e_1 \text{ do } \mathcal{I}[s_1] \text{ loop } \mathcal{I}[s_2] \text{ until } e_2$
$\mathcal{I}[\text{construct } c \ x \ s \ \text{destruct } x]$	$= \text{construct } c \ x \ \mathcal{I}[s] \ \text{destruct } x$
$\mathcal{I}[\text{local } t \ x = e \ s \ \text{delocal } t \ x = e]$	$= \text{local } t \ x = e \ \mathcal{I}[s] \ \text{delocal } t \ x = e$

Figure 2.27: ROOPL++ statement inverter, extended from [11]

Program inversion is conducted by recursive descent over components and statements. A proposed extension to the statement inverter for whole-program inversion is retained in the ROOPL++ statement inverter. The extension covers a case that reveals itself during method calling. As a method call is equivalent to an uncall with the inverse method we simply change calls to uncalls during inversion, the inversion of the method body cancels out. The proposed extension, presented in [31, 11], simply avoids inversion of calls and uncalls, as shown in figure 2.28.

2.10.1 Invertibility of Statements

While the invertibility of statements remains untouched by the extensions made in ROOPL++, the following proof, originally presented in [11], has been included for completeness.

$$\begin{aligned}
\mathcal{I}'[\mathbf{call}\ q(\dots)] &= \mathbf{call}\ q(\dots) & \mathcal{I}'[\mathbf{call}\ x :: q(\dots)] &= \mathbf{call}\ x :: q(\dots) \\
\mathcal{I}'[\mathbf{uncall}\ q(\dots)] &= \mathbf{uncall}\ q(\dots) & \mathcal{I}'[\mathbf{uncall}\ x :: q(\dots)] &= \mathbf{uncall}\ x :: q(\dots) \\
\mathcal{I}'[s] &= \mathcal{I}[s]
\end{aligned}$$

Figure 2.28: Modified statement inverter for statements, originally from [11]

If execution of a statement s in store μ yields μ' , then execution of the inverse statement, $\mathcal{I}[s]$ in store μ' should yield μ . Theorem 2.1 shows that \mathcal{I} is a statement inverter.

Theorem 2.1. (*Invertibility of statements, originally from [11]*)

$$\overbrace{\langle l, \gamma \rangle \vdash_{\text{stmt}}^{\Gamma} s : \mu \rightleftharpoons \mu'}^{\mathcal{S}} \iff \overbrace{\langle l, \gamma \rangle \vdash_{\text{stmt}}^{\Gamma} \mathcal{I}[s] : \mu' \rightleftharpoons \mu}^{\mathcal{S}'}$$

Proof. By structural induction on the semantic derivation of \mathcal{S} (omitted). It suffices to show that $\mathcal{S} \implies \mathcal{S}'$, as this can serve as proof of $\mathcal{S}' \implies \mathcal{S}$, as \mathcal{I} is an involution.

2.10.2 Type-Safe Statement Inversion

Given a well-typed statement, the statement inverter \mathcal{I} should always produce a well-typed, inverse statement in order to correctly support backwards determinism of injective functions. Theorem 2.2 describes this.

Theorem 2.2. (*Inversion of well-typed statements, originally from [11]*)

$$\overbrace{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} s}^{\mathcal{T}} \implies \overbrace{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} \mathcal{I}[s]}^{\mathcal{T}'}$$

Proof. By structural induction on \mathcal{T} . Unmodified ROOPL statements retained in ROOPL++ has been omitted.

- Case $\mathcal{T} =$

$$\frac{\overbrace{\Pi \vdash_{\text{expr}} e_1 : \mathbf{int}}^{\mathcal{E}_1} \quad \overbrace{\left(x \cup \text{vars}(e_1) \right) \cap \text{vars}(e_2) = \emptyset}^{\mathcal{C}_2} \quad \overbrace{\Pi \vdash_{\text{expr}} e_2 : \mathbf{int}}^{\mathcal{E}_2}}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} x[e_1] \odot = e_2} \text{T-ARRELEMASS}$$

In this case, we have $\mathcal{I}[x \odot = e] = x \odot' = e$, for some \odot' . Therefore, \mathcal{T}' will also be a derivation of rule T-ARRELEMASS, and as such, we can simply reuse the conditions $\mathcal{C}_1, \mathcal{C}_2$

and the expressions $\mathcal{E}_1.\mathcal{E}_2$ in construction of \mathcal{T}'

$$\mathcal{T}' = \frac{\overbrace{\Pi \vdash_{expr} e_1 : \mathbf{int}}^{\mathcal{E}_1} \quad \overbrace{\left(x \cup \text{vars}(e_1) \right) \cap \text{vars}(e_2) = \emptyset}^{\mathcal{C}_2} \quad \overbrace{\Pi \vdash_{expr} e_2 : \mathbf{int}}^{\mathcal{E}_2}}{\langle \Pi, c \rangle \vdash_{stmt}^\Gamma x[e_1] \odot' = e_2}$$

- Case $\mathcal{T} = \frac{\overbrace{\Pi(x) = c'}^{\mathcal{C}_1}}{\langle \Pi, c \rangle \vdash_{stmt}^\Gamma \mathbf{new} \ c' \ x} \text{T-ObjNew}$

In this case we have $\mathcal{I}[\mathbf{new} \ c \ x] = \mathbf{delete} \ c \ x$, meaning \mathcal{T}' must be of the form:

$$\mathcal{T}' = \frac{\overbrace{\Pi(x) = c'}^{\mathcal{C}_2}}{\langle \Pi, c \rangle \vdash_{stmt}^\Gamma \mathbf{delete} \ c' \ x}$$

- Case $\mathcal{T} = \frac{\overbrace{\Pi(x) = c'}^{\mathcal{C}_1}}{\langle \Pi, c \rangle \vdash_{stmt}^\Gamma \mathbf{delete} \ c' \ x} \text{T-ObjDLT}$

Inverse of the previous case, we now have $\mathcal{I}[\mathbf{delete} \ c \ x] = \mathbf{new} \ c \ x$, meaning \mathcal{T}' must be of the form:

$$\mathcal{T}' = \frac{\overbrace{\Pi(x) = c'}^{\mathcal{C}_2}}{\langle \Pi, c \rangle \vdash_{stmt}^\Gamma \mathbf{new} \ c' \ x}$$

- Case $\mathcal{T} = \frac{\overbrace{\text{arrayType}(a) \in \{\text{classIDs}, \mathbf{int}\}}^{\mathcal{C}_1} \quad \overbrace{\Pi \vdash_{expr} e = \mathbf{int}}^{\mathcal{E}} \quad \overbrace{\Pi(x) = a[\]}^{\mathcal{C}_2}}{\langle \Pi, c \rangle \vdash_{stmt}^\Gamma \mathbf{new} \ a[e] \ x} \text{T-ARRNew}$

In this case we still have $\mathcal{I}[\mathbf{new} \ c \ x] = \mathbf{delete} \ c \ x$. Using \mathcal{C}_1 and \mathcal{E} , \mathcal{T}' must be of the form:

$$\mathcal{T}' = \frac{\overbrace{\text{arrayType}(a) \in \{\text{classIDs}, \mathbf{int}\}}^{\mathcal{C}_1} \quad \overbrace{\Pi \vdash_{expr} e = \mathbf{int}}^{\mathcal{E}} \quad \overbrace{\Pi(x) = a[\]}^{\mathcal{C}_3}}{\langle \Pi, c \rangle \vdash_{stmt}^\Gamma \mathbf{delete} \ a[e] \ x}$$

- Case $\mathcal{T} = \frac{\overbrace{\text{arrayType}(a) \in \{\text{classIDs}, \mathbf{int}\}}^{\mathcal{C}_1} \quad \overbrace{\Pi \vdash_{expr} e = \mathbf{int}}^{\mathcal{E}} \quad \overbrace{\Pi(x) = a[\]}^{\mathcal{C}_2}}{\langle \Pi, c \rangle \vdash_{stmt}^\Gamma \mathbf{delete} \ a[e] \ x} \text{T-ARRDLT}$

Similar to the object deletion case, we still have $\mathcal{I}[\text{delete } c \ x] = \text{new } c \ x$. Using \mathcal{C}_1 and \mathcal{E} , \mathcal{T}' must be of the form:

$$\mathcal{T}' = \frac{\overbrace{\text{arrayType}(a) \in \{\text{classIDs}, \text{int}\}}^{\mathcal{C}_1} \quad \overbrace{\Pi \vdash_{\text{expr}} e = \text{int}}^{\mathcal{E}} \quad \overbrace{\Pi(x) = a[\]}^{\mathcal{C}_3}}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} \text{new } a[e] \ x}$$

- Case $\mathcal{T} = \frac{\overbrace{\Pi(x) = c'}^{\mathcal{C}_1} \quad \overbrace{\Pi(x') = c'}^{\mathcal{C}_2}}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} \text{copy } c' \ x \ x'} \text{T-CP}$

We have $\mathcal{I}[\text{copy } c \ x \ x'] = \text{uncopy } c \ x \ x'$. Using \mathcal{C}_1 , \mathcal{T}' must as such be of the form

$$\mathcal{T}' = \frac{\overbrace{\Pi(x) = c'}^{\mathcal{C}_1} \quad \overbrace{\Pi(x') = c'}^{\mathcal{C}_3}}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} \text{uncopy } c' \ x \ x'}$$

- Case $\mathcal{T} = \frac{\overbrace{\Pi(x) = c'}^{\mathcal{C}_1} \quad \overbrace{\Pi(x') = c'}^{\mathcal{C}_2}}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} \text{uncopy } c' \ x \ x'} \text{T-UCP}$

We have $\mathcal{I}[\text{uncopy } c \ x \ x'] = \text{copy } c \ x \ x'$. Using \mathcal{C}_1 , \mathcal{T}' must as such be of the form

$$\mathcal{T}' = \frac{\overbrace{\Pi(x) = c'}^{\mathcal{C}_1} \quad \overbrace{\Pi(x') = c'}^{\mathcal{C}_3}}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} \text{copy } c' \ x \ x'}$$

- Case $\mathcal{T} = \frac{\overbrace{\langle \Pi, c \rangle \vdash_{\text{expr}}^{\Gamma} e_1}^{\mathcal{E}_1} \quad \overbrace{\langle \Pi[x \mapsto c'], c \rangle \vdash_{\text{stmt}}^{\Gamma} s}^{\mathcal{S}} \quad \overbrace{\langle \Pi, c \rangle \vdash_{\text{expr}}^{\Gamma} e_2}^{\mathcal{E}_2}}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} \text{local } c' \ x = e_1 \quad s \quad \text{delocal } c' \ x = e_2} \text{T-LOCALBLOCK}$

We have $\mathcal{I}[\text{local } t \ x = e \quad s \quad \text{delocal } t \ x = e] = \text{local } t \ x = e \quad \mathcal{I}[s] \quad \text{delocal } t \ x = e$.

By the induction hypothesis on \mathcal{S} , we obtain \mathcal{S}' of $\langle \Pi[x \mapsto c'], c \rangle \vdash_{\text{stmt}}^{\Gamma} \mathcal{I}[s]$. Using \mathcal{E}_1 , \mathcal{S}' and \mathcal{E}_2 we construct \mathcal{T}'

$$\mathcal{T}' = \frac{\overbrace{\langle \Pi, c \rangle \vdash_{\text{expr}}^{\Gamma} e_1}^{\mathcal{E}_1} \quad \overbrace{\langle \Pi[x \mapsto c'], c \rangle \vdash_{\text{stmt}}^{\Gamma} \mathcal{I}[s]}^{\mathcal{S}'} \quad \overbrace{\langle \Pi, c \rangle \vdash_{\text{expr}}^{\Gamma} e_2}^{\mathcal{E}_2}}{\langle \Pi, c \rangle \vdash_{\text{stmt}}^{\Gamma} \text{local } c' \ x = e_1 \quad \mathcal{I}[s] \quad \text{delocal } c' \ x = e_2}$$

Using these added cases to the original proof provided in [11], Theorem 2.2 shows that well-typedness is preserved over inversion of ROOPL++ methods. As methods are well-typed if their body statement is well-typed, inversion of classes and programs also preserve well-typedness, as classes consists of methods and programs of classes, by using the class inverter presented in figure 2.28.

2.11 Computational Strength

Traditional, non-reversible programming languages have their computational strength measured in terms of their abilities to simulate the Turing machine (TM). If any arbitrary Turing machine can be implemented in some programming language, the language is said to be computationally universal or Turing-complete. In essence, Turing-completeness marks when a language can compute all computable functions. Reversible programming languages, like JANUS, ROOPL and ROOPL++, are not Turing-complete as they only are capable of computing injective, computable functions.

For determining computing strength of reversible programming languages, Yokoyama et al. suggests that the reversible Turing machine (RTM) could serve as the baseline criterion [29]. As such, a reversible programming language is reversibly universal or r-Turing complete if it is able to simulate a reversible Turing machine cleanly, i.e. without generating garbage data. If garbage was on the tape, the function simulated by the machine would not be an injective function and as such, no garbage should be left after termination of the simulation.

2.11.1 Reversible Turing Machines

Before we show that ROOPL++ in fact is r-Turing complete, we present the formalized reversible Turing machine definition, as defined in [29].

Definition 2.1. (*Quadruple Turing Machine*)

A TM T is a tuple $(Q, \Gamma, b, \delta, q_s, q_f)$ where

Q is the finite non-empty set of states

Γ is the finite non-empty set of tape alphabet symbols

$b \in \Gamma$ is the blank symbol

$\delta : (Q \times \Gamma \times \Gamma \times Q) \cup (Q \times \{/\} \times \{L, R\} \times Q)$ is the partial function representing the transitions

$q_s \in Q$ is the starting state

$q_f \in Q$ is the final state

The symbols L and R represent the tape head shift-directions left and right. A quadruple is either a symbol rule of the form (q_1, s_1, s_2, q_2) or a shift rule of the form $(q_1, /, d, q_2)$ where $q_1 \in Q$, $q_2 \in Q$, $s_1 \in \Gamma$, $s_2 \in \Gamma$ and d being either L or R .

A symbol rule (q_1, s_1, s_2, q_2) means that in state q_1 , when reading s_1 from the tape, write s_2 to the tape and change to state q_2 . A shift rule $(q_1, /, d, q_2)$ means that in state q_1 , move the tape head in direction d and change to state q_2 .

Definition 2.2. (*Reversible Turing Machine*)

A TM T is a reversible TM iff, for any distinct pair of quadruples $(q_1, s_1, s_2, q_2) \in \delta_T$ and $(q'_1, s'_1, s'_2, q'_2) \in \delta_T$, we have

$$q_1 = q'_1 \implies (t_1 \neq / \wedge t'_1 \neq / \wedge t_1 \neq t'_1) \text{ (forward determinism)}$$

$$q_2 = q'_2 \implies (t_1 \neq / \wedge t'_1 \neq / \wedge t_2 \neq t'_2) \text{ (backward determinism)}$$

A RTM simulation implemented in ROOPL by representing the set of states $\{q_1, \dots, q_n\}$ and the tape alphabet Γ as integers and the rule $/$ and direction symbols L and R as the uppercase integer literals **SLASH**, **LEFT** and **RIGHT** was presented in [11]. As ROOPL contains no array or stack primitives, the transition table δ was suggested to be represented as a linked list of objects containing four integers **q1**, **s1**, **s2** and **q2** each, where **s1** equals **SLASH** for shift rules. In ROOPL++, we do, however, have an array primitive and as such, we can simply simulate transitions by having rules **q1**, **s1**, **s2** and **q2** represented as arrays, where the number of cells in each array is **PC_MAX**, in a similar fashion as shown in [29].

2.11.2 Tape Representation

As with regular Turing machines, the Reversible Turing machines also have tapes of infinite length. Therefore, we must simulate tape growth in either direction. Yokoyama et al. represented the tape using two stack primitives in the Janus RTM interpreter and Haulund used list of objects. In ROOPL++, we could implement a stack, as objects are not statically scoped as in ROOPL. However, in terms of easy of use, a doubly linked list implementation similar to the one presented in section 2.7.3, of simple cell objects containing *value*, *left*, *right* and *self* fields, is more intuitive.

As such, the tape head finds a tape cell by inspecting a specific element of the doubly linked list tape representation. When we move in either direction, we simply set the neighbour element as the new tape head and allocate a new neighbour for the new tape head cell, if we are at the end of the list, to simulate the infinitely-length tape. Reversibly, this means that when we move in the opposite direction, blank cells are deallocated if we are moving the tape head away from the cell currently neighbouring either end of the tape.

Figure 2.29 shows the *moveRight* method for moving the tape head right. If the current tape head has no instantiated right neighbour we construct one using the **new** statement. Uncalling this method will move the tape head left. If the tape head is empty after moving left, we simply allocate a new cell, thus allowing tape growth in both directions.

```

1 method moveRight(int symbol, Cell tapeHead)
2   local Cell right = nil
3   local Cell tmp = nil
4   uncall tapeHead::getSymbol(symbol) // Put symbol back in current cell
5   call tapeHead::getRight(right)    // Get right neighbour
6
7   if right = nil && symbol = BLANK then
8     symbol ^= BLANK // Zero clear symbol
9     new Cell right // Init new neighbour
10    copy Cell right tmp // Copy reference to self
11    uncall right::getSelf(tmp) // Store self reference
12    uncall right::getLeft(tapeHead) // Set tape head as left of new cell
13    right <=> tapeHead
14  else
15    call right::getLeft(tmp) // Get copy of tape head reference
16    uncopy Cell tmp tapeHead // Clear reference to tape head
17
18    if tapeHead = nil && symbol = BLANK
19      call tmp::getSelf(tapeHead) // rev: set self pointer
20      uncopy Cell tmp tapeHead // rev: new self pointer
21      delete Cell tmp // rev: new left neighbour
22      symbol ^= BLANK
23    else skip // In reverse:
24    fi tmp = nil // Allocate new left if current is nil
25
26    uncall right::getLeft(tmp) // Put tape head reference back
27    tapeHead <=> right
28    call tapeHead::getRight(right) // Get right of new tape head
29    call tapeHead::getSymbol(symbol) // Get symbol of new tape head
30  fi right = nil
31  uncall tapeHead::getRight(right) // Set right neighbour
32  delocal Cell right = nil
33  delocal Cell tmp = nil

```

Figure 2.29: Method for moving the tape head in the RTM simulation

2.11.3 Reversible Turing Machine Simulation

Figure 2.30 shows the modified method *inst* from [29], which executes a single instruction given the tape head, the current state, symbol, program counter and the four arrays representing the transition rules. As described above, we **call** *moveRight* to move the tape head right and **uncall** to move the tape head left.

Figure 2.31 shows the *simulate* method which is the main method responsible for running the RTM simulation. The tape is extended in either direction when needed, and the program counter is incremented.

Unlike the ROOPL simulation, ROOPL++ is not limited by stack allocated, statically-scoped objects. Due to this limitation, the ROOPL RTM simulator cannot finish with the TM tape as its program output when the RTM halts, as the call stack of the simulation must unwind before termination. As objects in ROOPL++ are not bound by this limitation, the TM tape will exist as the program output when the RTM halts.¹

Instantiating a RTM simulation consists of initializing an initial tape head cell, as well as the

¹We are here breaking the rule that a **new** statement must eventually be followed by a **delete** statement to free the data.

```

1 method inst(int state, int symbol, int[] q1, int[] s1,
2             int[] s2, int[] q2, int pc, Cell tapeHead)
3     if state = q1[pc] && symbol = s1[pc] then // Symbol rule:
4         state += q2[pc]-q1[pc] // set state to q2[pc]
5         symbol += s2[pc]-s1[pc] // set symbol to s2[pc]
6     fi state = q2[pc] && symbol = s2[pc]
7     if state = q1[pc] && s1[pc] = SLASH then // Move rule:
8         state += q2[pc]-q1[pc] // set state to q2[pc]
9         if s2[pc] = RIGHT then
10             call moveRight(symbol, tapeHead) // Move tape head right
11         fi s2[pc] = RIGHT
12         if s2[pc] = LEFT then
13             uncall moveRight(symbol, tapeHead) // Move tape head left
14         fi s2[pc] = LEFT
15     fi state = q2[pc] && s1[pc] = SLASH

```

Figure 2.30: Method for executing a single TM transition

```

1 method simulate(Cell tapeHead, int state, int[] q1, int[] s1, int[] s2, int[] q2, int pc)
2     from state = Qs do
3         pc += 1 // Increment pc local int symbol = 0
4         call tapeHead::getSymbol(symbol) // Fetch current symbol
5         call inst(state, symbol, q1, s1, s2, q2, pc, tapeHead)
6         uncall tapeHead::getSymbol(symbol) // Zero-clear symbol delocal symbol = 0
7         if pc = PC_MAX then // Reset pc
8             pc ^= PC_MAX
9         else skip
10        fi pc = 0
11    loop skip
12    until state = Qf

```

Figure 2.31: Main RTM simulation method

transition rule arrays. After initialization, the *simulate* method is simply called and the simulation begins.

Dynamic Memory Management

In order to allow objects to live outside of static scopes, we need to utilize a different memory management technique, such that objects are not allocated on the stack. Dynamic memory management presents a method of storing objects in different memory structures, most commonly, a memory heap. Most irreversible, modern programming languages use dynamic memory management in some form for allocating space for objects in memory.

However, reversible, native support for complex data structures is a non-trivial matter to implement. Variable-sized records and frames need to be stored efficiently in a structured heap, while avoiding garbage build-up to maintain reversibility. A reversible heap manager layout has been proposed for a simplified version of the reversible functional language RFUN and later expanded to allow references to avoid deep copying values [2, 30, 18].

This chapter presents a brief introduction to fragmentation, garbage and linearity and how these respectively are handled reversibly, and a discussion of various heap manager layouts considered for ROOPL++, along with their advantages and disadvantages in terms of implementation difficulty, garbage build-up and the OOP paradigm.

3.1 Fragmentation

Efficient memory usage is an important matter to consider when designing a heap layout for a dynamic memory manager. In a stack allocating memory layout, the stack discipline is in effect, meaning only the most recently allocated data can be freed. This is not the case with heap allocation, where data can be freed regardless of allocation order. A potential side effect of this freedom, comes as a consequence of memory fragmentation. We distinguish different types of fragmentation as internal or external fragmentation.

Internal fragmentation refers to unused space inside a memory block used to store an object, if, say, the object is smaller than the block it has been allocated to. External fragmentation occurs as blocks freed throughout execution are spread across the memory heap, resulting in *fragmented* free space [20].

3.1.1 Internal Fragmentation

Internal fragmentation occurs in the memory heap when part of an allocated memory block is unused. This type of fragmentation can arise from a number of different scenarios, but mostly it originates from cases of *over-allocation*, which occurs when the memory manager delegates memory larger than required to fit an object, due to e.g. fixed-block sizing.

For an example, consider a scenario, in which we allocate memory for an object of size m onto a simple, fixed-sized block heap. The fixed block size is n and $m \neq n$. If $n > m$, internal fragmentation would occur of size $n - m$ for every object of size m allocated in said heap. If $n < m$, numerous blocks would be required for allocation to fit our object. In this case the internal fragmentation would be of size $n - m \bmod n$ per allocated object of size m .

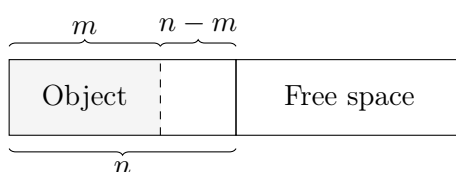


Figure 3.1a: Creation of internal fragmentation of size $n - m$ due to *over-allocation*

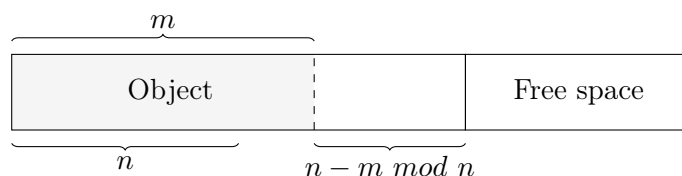


Figure 3.1b: Creation of internal fragmentation of size $n - m \bmod n$ due to *over-allocation*

Figure 3.1a and 3.1b visualize the examples of internal fragmentation build-up from *over-allocating* memory.

It is difficult for the memory manager to reclaim wasted memory caused by internal fragmentation, as it usually originates from a design choice. Intuitively, internal fragmentation can best be prevented by ensuring that the size of block(s) being used for allocating space for an object of size m either match or sums to this exact size, when designing the layout.

3.1.2 External Fragmentation

External fragmentation materializes in the memory heap when a freed block becomes partly or completely unusable for future allocation if, say, it is surrounded by allocated blocks but the size of the freed block is too small to contain objects on its own.

This type of fragmentation is generally a more substantial cause of problems than internal fragmentation, as the amount of wasted memory typically is larger and less predictable in external fragmentation blocks than in internal fragmentation blocks. Depending on the heap implementation, i.e. a layout using variable-sized blocks of, say, size 2^n , the internal fragment size becomes considerable for large values of n .

Non-allocatable external fragments become a problem when it is impossible to allocate space for a large object as a result of too many non-consecutive blocks scattered around the heap, caused by the external fragmentation. Physically, there is enough space to store the object, but not in the current heap state. In this scenario we would need to relocate blocks in such a manner that the fragmentation disperses, which is not possible to do reversibly.

Allocation and deallocation order is important in order to combat external fragmentation. For example, if we have a class A , which fit on one memory block of size n , and we have a class B , which fit on two memory blocks of size n and limited memory space, we can easily reach a situation, where we cannot fit more B objects due to external fragmentation.

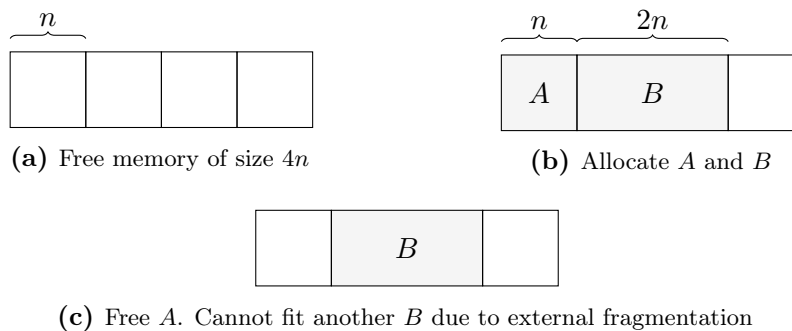


Figure 3.2: Example of external fragmentation caused for allocation and deallocation order

Figure 3.2 shows this example, where the allocation and deallocation order causes a situation, in which we cannot allocate any more B objects, even though we physically have the required amount of free space in memory.

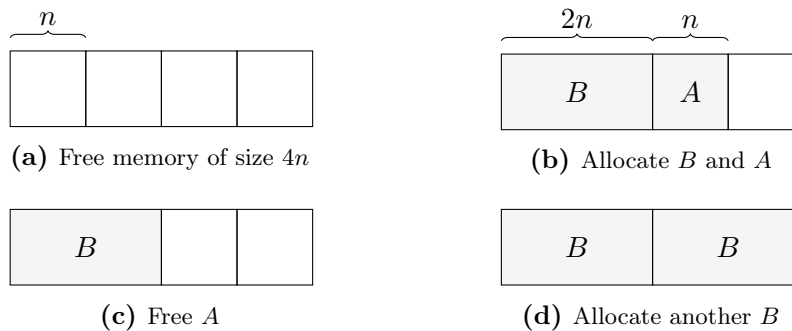


Figure 3.3: Example of avoiding external fragmentation using allocation and deallocation order

Figure 3.3 shows how changing allocation and deallocation order can combat external fragmentation.

3.2 Memory Garbage

A reversible computation should be garbage-free and as such it should be our goal to return the memory to its original state after program termination.

Traditionally, in non-reversible programming languages, freed memory blocks are simply re-added to the free list during deallocation and no modification of the actual data stored in the block is performed, as it simply is overwritten when the block is used later on. In the reversible setting we must return the memory block to its original state after the block has been freed (e.g. zero-cleared), to uphold the time-invertible and two-directional computational model. Figure 3.4 illustrates how the output data (or garbage) of an injective function f is the input to its inverse function f^{-1} .

In heap allocation layouts, we maintain one or more free lists to keep track of free blocks during program execution, which are stored in memory, besides the heap representation itself. These free lists can essentially be considered garbage and as such, they must also be returned to their original state after execution. Furthermore, the heap itself can also be considered garbage and if it grows during execution, it should also be returned to its original size.

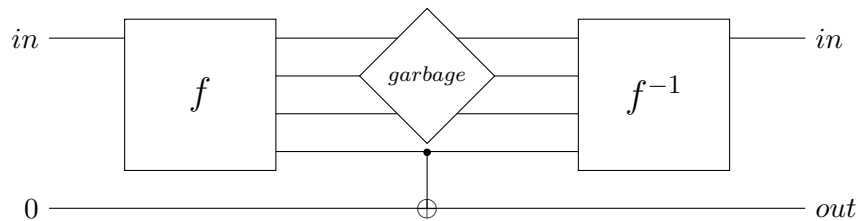


Figure 3.4: The "garbage" output of an injective function f is the input to its inverse function f^{-1}

Returning the free list(s) to their original states is a non-trivial matter, which is highly dependent on the heap layout and free list design. Axelsen and Glück introduced a dynamic memory manager which allowed heap allocation and deallocation, but without restoring the free list to its original state in [2]. Axelsen and Glück argue that an unrestored free list can be considered harmless garbage in the sense that the free list residing in memory after termination is equivalent to a restored free list, as it contains the same blocks, but linked in a different order, depending on the order of allocation and deallocation operations performed during program execution. Figure 3.5 illustrates how an inverse, injective function f^{-1} , whose non-inverse function f computes something which modifies a given free lists, does not require the *exact* output free list of f , but *any* free list of same layout as input for the inverse function f^{-1} . The output free list of f^{-1} will naturally be a further modified free list.

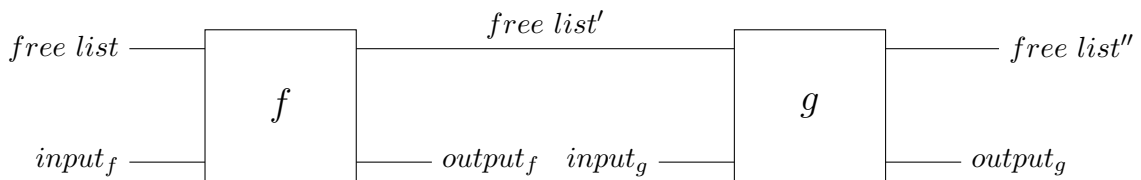


Figure 3.5: All free lists are considered equivalent "garbage" in terms of injective functions

This intuitively leads to the question of garbage classification. In the reversible setting all functions are injective. Thus, given some $input_f$, in a reversible computation using heap allocation, the injective function f produces some $output_f$ and some modified free list $free\ list'$, obtained after storing or freeing data in the heap during the execution of f with an input $free\ list$. A future injective function in the program, function g , must thus take any modification of the original

free list in addition to its input to produce its output $output_g$ and a potentially further modified free list, *free list''*. However, in the context of reversible heaps, we must consider all free lists as of equivalent, harmless garbage class and thus freely substitutable with each other, as injective functions still can drastically change the block layout, free list order, etc. during its execution in either direction. Figure 3.5 shows how any free list can be passed between a function f and a function g further in the program.

3.3 Linearity and Reference Counting

Programming languages use different approaches for storing and synchronizing variables and objects in memory. Typing *linearity* is a distinction, which can reduce storage management and synchronization costs [4].

Reversible programming languages such as JANUS and ROOPL are linear in the sense that object and variable pointers cannot be copied and are only deleted during deallocation. Pointer copying greatly increases the flexibility of programming, especially in a reversible setting where zero-clearing is critical, at the cost of increased management in form of reference counting for e.g. objects. For variables, pointer copying is not particularly interesting, nor would it add much flexibility as the values of a variable simply can be copied into statically-scoped local blocks. For objects however, tedious amounts of boilerplate work must be done if object A and B need to work on the same object C and only one reference to each object is allowed. Copying is not an option as field modification in one copy does not affect the other copies.

Mogensen presented the reversible functional language RCFUN which use reference counting to allow multiple pointers to the same memory nodes as well as a translation from RCFUN into JANUS in [18]. In RCFUN, reference counting is used to manage and trace the number of pointer copies made by respectively incrementing and decrementing a *reference count* stored in the memory node, whenever the original node pointer is copied or a copy pointer is deleted. For the presented heap manage, deletion of object nodes was only allowed when no references to a node remained.

In non-reversible languages, reference counting is also used in garbage collection by automatically deallocating unreachable objects and variables which contains no referencing.

3.4 Heap Manager Layouts

Heap managers can be implemented in numerous ways. Different layouts yield different advantages when allocating memory, finding a free block or when collecting garbage. As our goal is to construct a garbage-free heap manager, our finalized design should emphasize and reflect this objective in particular. Furthermore, we should attempt to allocate and deallocate memory as efficiently as possible, as merging and splitting of blocks is a non-trivial problem in a reversible setting and to avoid problematic fragmentation.

For the sake of simplicity, we will not consider the issue of retrieving memory pages reversibly. A reversible operating system is a long-term dream of the reversible researcher and as reversible programming language designers, we assume that ROOPL++ will be running in an environment,

in which an operating system will be supplying memory pages and their mappings. As such, the following heap memory designs reflect this preliminary assumption, that we can always query the operating system for more memory.

Historically, most object-oriented programming languages utilize a dynamic memory manager during program execution. In lower-level languages such as C or C++, memory management is manual and allocation has to be stated explicitly and with the requested size through the **malloc** statement and deallocated using the **free** statement. Modern languages, such as JAVA and PYTHON, *automagically* allocates and frees space for objects and variable-sized arrays by utilizing their dynamic memory manager and garbage collector to dispatch **malloc**- and **free**-like operations to the operating system and managing the obtained memory blocks in private heap(s) [15, 25, 21]. The heap layout of these managers vary from language to language and compiler to compiler.

Previous work on reversible heap manipulation has been done for reversible functional languages in [2, 10, 19].

Axelsen and Glück presented a static heap structure consisting of LISP-inspired constructor cells of fixed size and a single free list for the reversible function language RFUN in [2]. Mogensen presented an implementation in JANUS of reversible reference counting under the assumption of Axelsen and Glück's heap manager in [18]. Building on the previous work, Mogensen later presented a reversible intermediate language RIL and an implementation in RIL of a reversible heap manager, which uses reference counting and hash-consing to achieve garbage collection in [19].

We do not consider reference counting or garbage collection in the layouts presented in the following sections, but we later show how the selected layout for ROOPL++ is extended with reference counting in section 4.7.

3.4.1 Memory Pools

The simplest heap layout we can design uses fixed-sized blocks. This design is also known as memory pools, as memory is allocated from "pools" of fixed-sized blocks regardless of the record size. To model these pools of fixed-sized blocks, we simply use a linked list of identically sized free block cells, which we maintain over execution. While the fixed-block layout is simple and relatively easy in terms of implementation it is also largely uninteresting as it provides little to no options, besides sizing of the fixed-blocks, to combat fragmentation.

This layout comes with a few options in terms of the actual heap layout. If we only allow allocation of consecutive, adjacent free blocks, we should keep the free list sorted. If the free list is not sorted, and we have to allocate an object which requires n blocks, we have to iterate the free list n^2 times in the worst case to find a chain of consecutive blocks large enough to fit the object. The sorting part itself is non-trivial matter. Furthermore, we need some overhead storage inside the object to contains the references of the blocks occupied by the object, or some other structure which can be used when deallocating the object and returning all the blocks to the free list. If we allow allocation of non-consecutive blocks, larger amounts of bookkeeping is required as we need to store knowledge of when and where the object is split.

Figures 3.2 and 3.3 from earlier in this chapter, in section 3.1.2 on page 47 illustrates examples with consecutive, fixed-sized block allocation.

3.4.2 One Heap Per Record Size

Instead of allocating space for objects from a single free list and heap, we could design an approach which uses one heap per record size, known as a multi-heap layout. The respective classes and their sizes are easily identified during compile time from which the amount of heaps and free list will be initialized. This means the layout is very dynamic and potentially can change drastically in terms of the amount of heaps utilized depending on the input program.

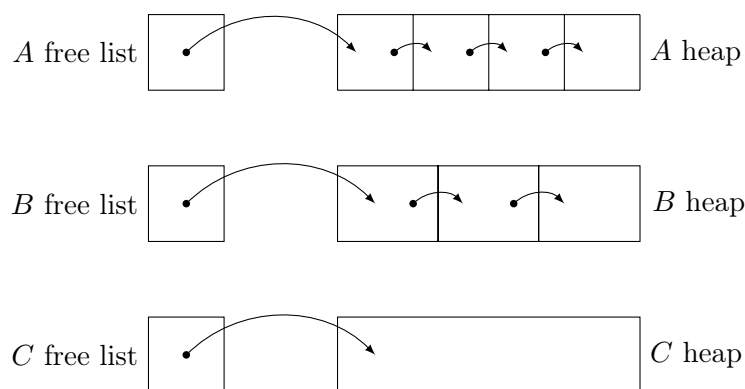


Figure 3.6: Memory layout using one heap per record size

Figure 3.6 illustrates three heaps with respective free lists for three classes A , B and C of size n , $2n$ and $4n$. Each heap is represented as a simple linked list with the free list simply being a pointer to the first free block in the heap.

The advantage of this approach would be effective elimination of internal and external fragmentation, as each heap fits their targeted record perfectly, making each allocation and deallocation tailored to the size of the record obtained from a static analysis during compilation, resulting in no over-allocation and no unusable chunks of freed memory appearing during varying deallocation order. Implementation-wise, allocation of an object of a given class simply becomes the task of popping the head of the respective free list, which can easily be determined at compile time. The deallocation is simply adding a new head to the free list.

Listing 3.1 outlines the allocation algorithm for this layout written in extended JANUS from [29]. We assume that the heads of the free lists are stored in a single array primitive, such that the free list for records of size n are indexed at $n - 2$ and $n > 2$ (as every record needs some overhead) and that we have heaps for continuous size range with no gaps.

The algorithm consists of an entry point named **malloc** and a recursion body named **malloc1**. Given a zero-cleared pointer p , the size of the object we are allocating o_{size} and the array of free lists primitive, the recursion body is called after initializing a *counter*, which is an index into the free lists array and a counter size, c_{size} , which is the block size of the current free list the *counter* is indexed in. The recursion body first updates the free list index until we find a free list with a size greater or equal to the size of the object we are allocating. Once such a free list

has been found, the head of the free list is simply popped and the next block is set as the new head.

```
1  procedure malloc(int p, int osize, int freelists[])
2      local int counter = 0
3      local int csize = 2
4      call malloc1(p, osize, freelists, counter, csize)
5      delocal int csize = 2
6      delocal int counter = 0
7
8  procedure malloc1(int p, int osize, int freelists[], int counter, int csize)
9      if (csize < osize) then
10         counter += 1
11         csize += 1
12         call malloc1(p, osize, freelists, counter, csize)
13         csize -= 1
14         counter -= 1
15     else
16         p += freelists[counter]
17         freelists[counter] -= p
18
19         // Swap head of free list with next block of p
20         freelists[counter] ^= M(p)
21         M(p) ^= freelists[counter]
22         freelists[counter] ^= M(p)
23     fi csize < osize
```

Listing 3.1: Allocation algorithm for one heap per record size implemented in extended Janus

The obvious disadvantage to this layout is the amount of bookkeeping and workload associated with growing and shrinking a heap and its neighbours, in case the program requests additional memory from the operating system. In real world object-oriented programming, most classes feature a small number of fields, very rarely more than 16.

Additionally, helper classes of other sizes would spawn additional heaps and bookkeeping work, making the encapsulation concept of OOP rather unattractive, for the optimization-oriented reversible programmer.

Finally, while internal and external fragmentation is effectively eliminated, we are left with additional and considerable amounts of garbage in forms of all the heaps and free lists initialized in memory. If two record types only differ one word in size, two heaps would be initialized. Each heap intuitively need to be initialized with a chunk of memory from the underlying operating system such that objects can be allocated on their respective heaps, regardless of the number of times the heap is used during program execution. This is an obvious space requirement increase over the previously presented layout, and on average, the amount of required memory for a program compiled using this approach would probably be larger, than some of the following layouts, due to unoptimized heap utilization and sharing. Heap of some sizes may be mostly empty when another is full, resulting in wasted memory.

3.4.3 One Heap Per Power-Of-Two

To address the issues of the previous heap manager layout, we can optimize the amounts of heaps required by introducing a relatively small amount of internal fragmentation. Instead of having a heap per record size, we could have a heap per power-of-two. Records would be stored in the heap closest to their respective size and, as such, we reduce the number of heaps needed, as

many different records can be stored in the same heap. Records of size 5, 6, 7 and 8 would in the former layout be stored in four different heaps, where they would be stored in a single heap using this layout. Figure 3.7 illustrates the free lists and heaps up to 2^n .

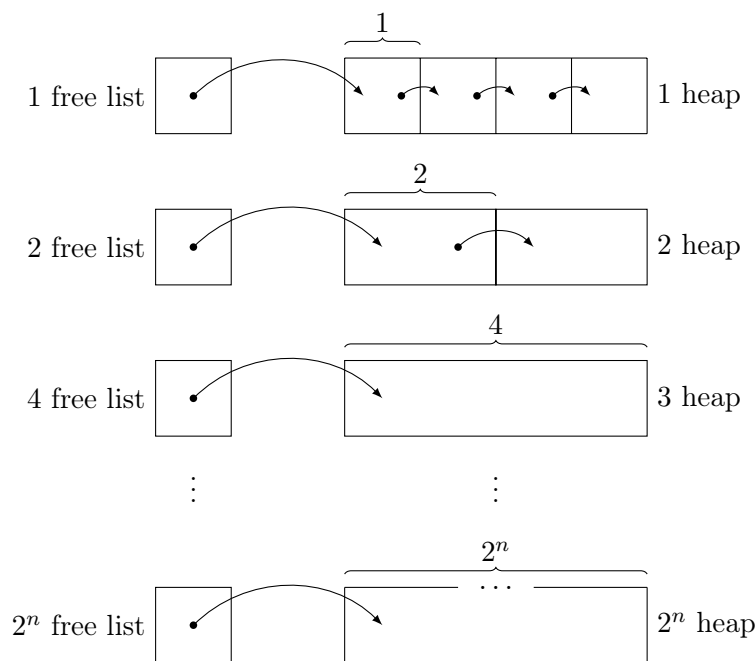


Figure 3.7: Memory layout using one heap per power-of-two

Internal fragmentation does become a problem for very large records, as blocks are only of size 2^n . An object of size 65 would fit in a 128 sized block, resulting in considerable amounts of wasted memory space in form of internal fragmentation. However, in the real world, most records are small and allocation of records causing this much amount of fragmentation is an unlikely scenario. To avoid large amounts of internal fragmentation building up when allocating large records, we could allocate space for large objects using smaller blocks. If a record exceeds some limit, which has been determined the cutoff point, one kilobyte for an example, we could split it into \sqrt{n} sized chunks and use blocks of that size instead. This would reduce the amount of internal fragmentation at the cost of increased bookkeeping. For smaller records, very minimal amounts of internal fragmentation occur.

The number of heaps needed for a computation can be determined at compile time by finding the smallest and largest record sizes and ensuring we have heaps to fit these effectively. The allocation process consists of determining the closest 2^n to the size of the record we are allocating and then simply popping the head of the respective free list.

Listing 3.2 shows a modified **malloc1** recursion body for the power-of-two approach. Once again, we assume our array of free lists contains the head of each free list, such that index n is the head of the free list of size 2^{n+1} . Instead of incrementing the counter size by one, as in the former layout algorithm, we double it, using the shown **double** procedure. Besides this change, the algorithm remains unchanged and still assumes each heap has been initialized along with the free lists.

```

1  procedure double(int target)
2      local int current = target
3      target += current
4      delocal int current = target / 2
5
6  procedure malloc1(int p, int osize, int freelists[], int counter, int csize)
7      if (csize < osize) then
8          counter += 1
9          call double(csize)
10         call malloc1(p, osize, freelists, counter, csize)
11         uncall double(csize)
12         counter -= 1
13     else
14         if freelists[counter] != 0 then
15             p += freelists[counter]
16             freelists[counter] -= p
17
18             // Swap head of free list with next block of p
19             freelists[counter] ^= M(p)
20             M(p) ^= freelists[counter]
21             freelists[counter] ^= M(p)
22         else
23             counter += 1
24             call double(csize)
25             call malloc1(p, osize, freelists, counter, csize)
26             uncall double(csize)
27             counter -= 1
28         fi freelists[counter] = 0 || p != freelists[counter]
29     fi csize < osize

```

Listing 3.2: Allocation algorithm for one heap per power-of-two implemented in extended Janus

3.4.4 Shared Heap, Record Size-Specific Free Lists

A natural proposal, considering the disadvantages of the previously presented designs, would be using a shared heap instead of record-specific heaps. This way, we ensure minimal fragmentation when allocating and freeing as the different free lists ensure that allocation of an object wastes as little memory as possible. By only keeping one heap, we eliminate the growth/shrinking issues of the multiple heap layout.

There is, however, still a considerable amount of bookkeeping involved in maintaining multiple free lists. Having mixed-size blocks in a single heap is also a task which might prove difficult to accomplish reversibly. How initialization and destruction of said heap should work is not clear. As with the multiple heap version of this layout, we are still left with the issues surrounding two records which only differs one word in size. In the former layout, two heaps were required to store records of these types. In this layout, we need to store two block sizes in our heap to allocate these records, with no internal fragmentation. We could allow these objects to be allocated on similarly-sized blocks, if we round the calculated class sizes up to, say, a power-of-two. We would essentially have a shared heap, power-of-two-specific free lists layout.

As the only change in this design are the heaps themselves, the allocation process remains unchanged from the one presented in listing 3.1 or listing 3.2 if we use the power-of-two approach. Figure 3.8 visualizes the shared heap and the free lists of this layout.

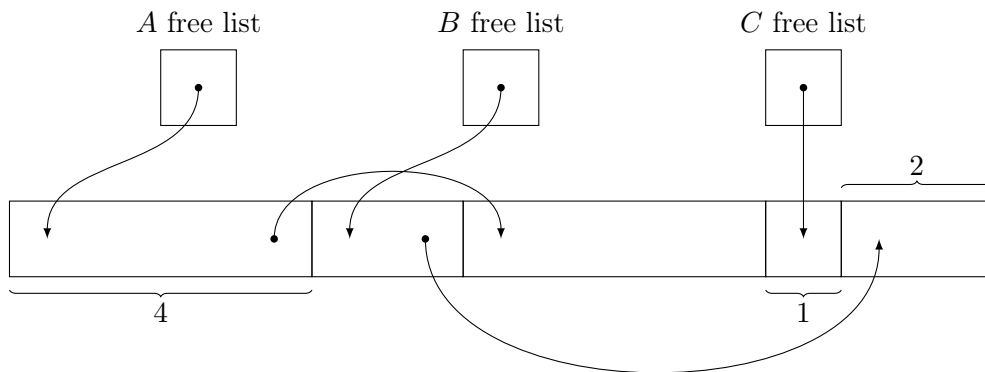


Figure 3.8: Record size-specific free lists on a shared heap (powers of two)

3.4.5 Buddy Memory

The Buddy Memory layout utilizes blocks of variable-sizes of the power-of-two, typically with one free list per power-of-two using a shared heap. When allocating an object of size m , we simply check the free lists for a free block of size n , where $n \geq m$. Is such a block found and if $n > m$, we split the block into two halves recursively, until we obtain the smallest block capable of storing m . When deallocating a block of size m , we do the action described above in reverse, thus merging the blocks again, where possible [13].

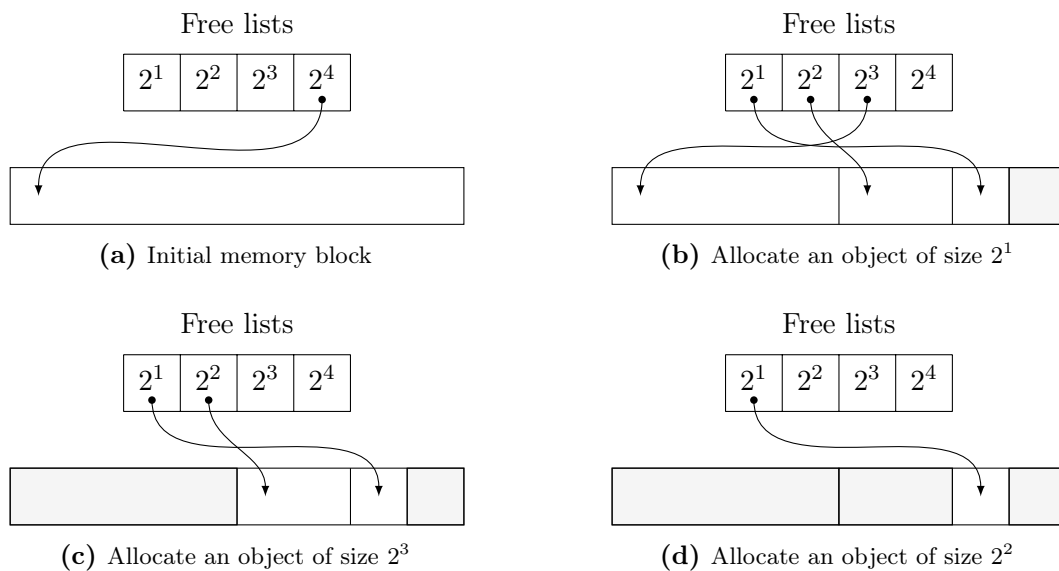


Figure 3.9: Buddy Memory block allocation example

Figure 3.9 illustrates an example of block splitting during allocation in the buddy system. Originally, one block of free memory is available. When allocating a record three factors smaller than the original block, three splits occurs.

This layout is somewhat of a middle ground between the previous three designs, addressing a number of problems found in these. The Buddy Memory layout uses a single heap for all

record-types, thus eliminating the problems related to moving adjacent heaps reversibly in a multi-heap layout. To optimize the problems around initializing a usable amount of variable-sized blocks in a shared heap, we simply initialize one large block in the buddy system, which we will split into smaller parts during execution and merge where possible when freed.

The main drawback from this layout is the amount of internal fragmentation. As we only allocate blocks of a power-of-two size, substantial internal fragmentation follows when allocating large records, i.e. allocating a block of size 128 for a record of size 65. However, as most real world programs uses much smaller sized records, we do not consider this a very frequent scenario. As discussed in section 3.4.3, we would split large records into chunks of \sqrt{n} at the cost of additional bookkeeping.

Implementation-wise, this design would require doubling and halving of numbers related to the power-of-two. This action translates well into the reversible setting, as a simply bit-shifting directly gives us the desired result.

```

1  procedure malloc1(int p, int osize, int freelists[], int counter, int csize)
2      if (csize < osize) then
3          counter += 1
4          call double(csize)
5          call malloc1(p, osize, freelists, counter, csize)
6          uncall double(csize)
7          counter -= 1
8      else
9          if freelists[counter] != 0 then
10             p += freelists[counter]
11             freelists[counter] -= p
12
13             // Swap head of free list with next block of p
14             freelists[counter] ^= M(p)
15             M(p) ^= freelists[counter]
16             freelists[counter] ^= M(p)
17          else
18             counter += 1
19             call double(csize)
20             call malloc1(p, osize, freelists, counter, csize)
21             uncall double(csize)
22             counter -= 1
23             freelists[counter] += p
24             p += csize
25          fi freelists[counter] = 0 || p - csize != freelists[counter]
26  fi csize < osize

```

Listing 3.3: The Buddy Memory algorithm implemented in extended Janus

Listing 3.3 shows the Buddy Memory algorithm implemented in the extended Janus variant with local blocks from [29]. For simplification, object sizes are rounded to the nearest power-of-two during compile-time. The algorithm extends on the one heap per power-of-two algorithm presented in listing 3.2, page 53. The body of the allocation function is still executed recursively until a free list for a 2^n larger than the size of the object has been found. Once found, we continue searching until we have found a non-empty free list. If the non-empty free list for a 2^n larger than the object is found, the head of the list is popped and the popped block is split recursively, until a block the desired size is obtained. Throughout the splitting process, empty free lists are updated when a larger free block is split into a block which fits into those lists.

Since a split block is always added as two blocks to an empty free list, we can only merge adjacent

blocks if they are the only two blocks in a free list.

Compilation

The following chapter presents the considerations and translation schemas used in the process of translating ROOPL++ to the reversible low-level machine language PISA. As ROOPL++ is an extension of ROOPL, many techniques are carried directly over, and have as such been left out.

Before presenting the ROOPL++ compiler, a brief overview of the memory layout and modeling of the ROOPL compiler, which the ROOPL++ compiler is a continuation of, is provided.

4.1 The ROOPL to PISA Compiler

Haulund presented a proof-of-concept compiler along with the design for ROOPL. The compiler translates well-typed ROOPL programs into the reversible machine language PISA in [11]. The ROOPL compiler (ROOPLC) is written in HASKELL and hosted at <https://github.com/TueHaulund/ROOPLC>.

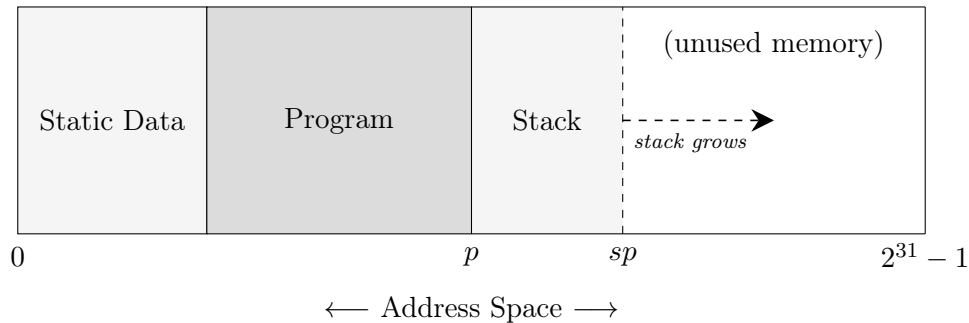


Figure 4.1: Memory layout of a ROOPL program, originally from [11]

Figure 4.1 shows the memory layout of a compiled ROOPL program. The layout consists of a static storage segment, the program segment and the stack.

The object model is simple and only features one additional word for storing the address of the virtual table for the object class. Figure 4.2 shows the prefixing for three simple classes modeling geometric shapes.

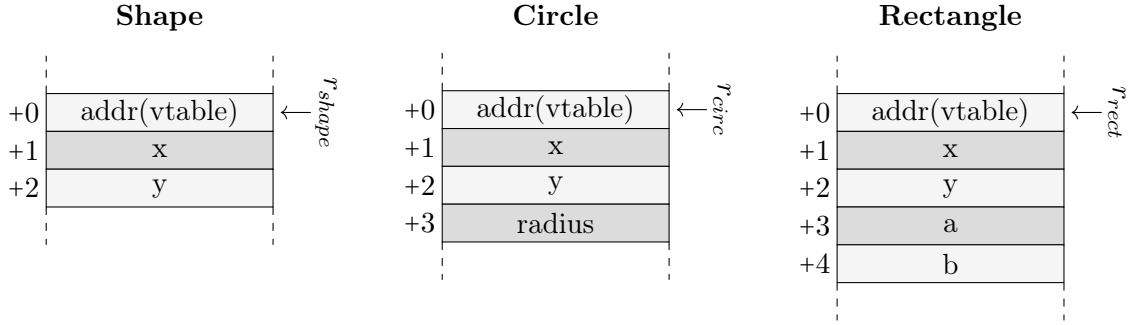


Figure 4.2: Illustration of prefixing in the memory layout of 3 ROOPL objects, originally from [11]

4.2 ROOPL++ Memory Layout

ROOPL++ builds upon the memory layout of its predecessor with dynamic memory management. The reversible Buddy Memory heap layout presented in section 3.4.5 is utilized in ROOPL++ as it is an interesting layout, addressing a number of disadvantages found in other considered layouts, naturally translates into a reversible setting with one simple restriction (i.e only blocks which are heads of their respectable free lists are allocatable) and since its only drawback is dismissible in most real world scenarios.

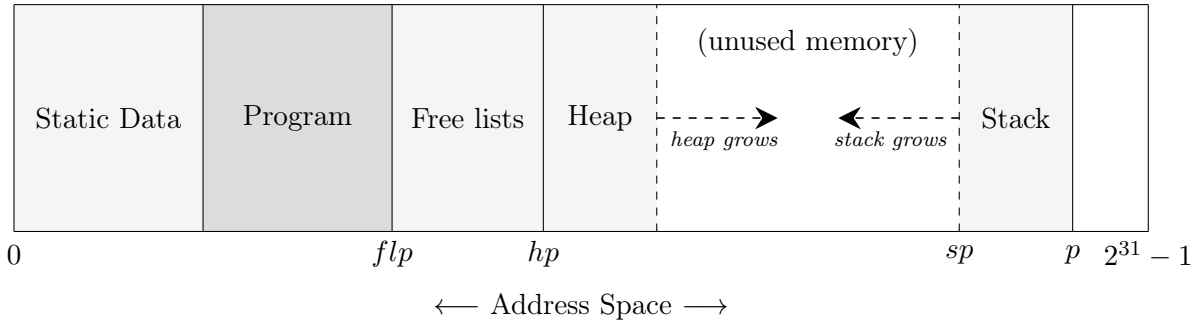


Figure 4.3: Memory layout of a ROOPL++ program

Figure 4.3 shows the full layout of a ROOPL++ program stored in memory.

- As with ROOPL, the static storage segment contains load-time labelled **DATA** pseudo-instructions, initialized with virtual function tables and other static data needed by the translated program.
- The program segment is stored right after the static storage and contains the translated ROOPL++ program instructions.
- The free lists maintained by the Buddy Memory heap layout is placed right after the program segment, with the *free list pointer* flp pointing at the first free list. The free lists are simply the address pointing to the first block of its respective size. The free lists are stored such that the free list at address $flp + i$ corresponds to the free list of size 2^{i+1} .
- The heap begins directly following the free lists. Its beginning is marked by the *heap pointer* (hp).

- Unlike in ROOPL, where the stack grows upwards, the ROOPL++ stack grows downwards and begins at address p . The stack remains a LIFO structure, analogously to ROOPL.

As mentioned in the previous chapter, we assume an underlying reversible operating system providing us with additional memory when needed. With no real way of simulating this, the ROOPL++ compiler places the stack at a fixed address p and sets one free block in the largest 2^n free list initially. The number of free lists and the address p is configurable in the source code, but defaults to 10 free lists, meaning initially one block of size 1024 is available and the stack is placed at address 1024 words after the heap.

In traditional compilers, the heap pointer usually points to the end of the heap. For reasons stated above, we never grow the heap as we start with a heap of fixed size. As such, the heap pointer simply points to the beginning of the heap.

The heap can simply be expanded by adding another block of the largest possible size and storing the address of the respective free list.

In the following sections of this chapter, we will present various translation techniques. In these translations, we will make use of a number of PISA pseudo-instructions to subtract integer values from registers and pushing/popping to the program stack. The pseudo-instructions are shown in figure 4.4 and are modified from [11], as the direction of the program stack is flipped in ROOPL++.

$$\begin{array}{ll}
 \text{SUBI} \quad r \quad i & \stackrel{\text{def}}{=} \quad \text{ADDI} \quad r \quad -i \\
 \\
 \text{PUSH} \quad r & \stackrel{\text{def}}{=} \quad \left[\text{EXCH} \quad r \quad r_{sp} , \quad \text{SUBI} \quad r_{sp} \quad 1 \right] \\
 \\
 \text{POP} \quad r & \stackrel{\text{def}}{=} \quad \left[\text{ADDI} \quad r_{sp} \quad 1 , \quad \text{EXCH} \quad r \quad r_{sp} \right]
 \end{array}$$

Figure 4.4: Definition of pseudoinstructions **SUBI**, **PUSH** and **POP**, modified from [11]

4.3 Inherited ROOPL features

As mentioned, a number of features from ROOPL carries over to ROOPL++.

The dynamic dispatching mechanism presented in [11] is inherited. As such, the invocation of a method implementation is based on the type of the object at run time. Virtual function tables are still the implementation strategy used in the dynamic dispatching implementation.

Evaluation of expressions and control flow remains unchanged.

For completeness, object blocks are included and still stack allocated as their life time is limited to the scope of their block and the dynamic allocation process is quite expensive in terms of register pressure and number of instructions compared to the stack allocated method implemented in the ROOPL compiler.

4.4 Program Structure

The program structure of a translated ROOPL++ is analogous to the program structure of a ROOPL program with the addition of free lists and heap initialization. The full structure is shown in figure 4.5.

(1)	.....	; Static data declarations
(2)	.....	; Code for program class methods
(3)	<i>start</i> : START	; Program starting point
(4)	ADDI r_{flps} p	; Initialize free lists pointer
(5)	XOR r_{hp} r_{flps}	; Initialize heap pointer
(6)	ADDI r_{hp} $size_{fls}$	; Initialize heap pointer
(7)	XOR r_b r_{hp}	; Store address of initial free memory block in r_b
(8)	ADDI r_{flps} $size_{fls}$	; Index to end of free lists
(9)	SUBI r_{flps} 1	; Index to last element of free lists
(10)	EXCH r_b r_{flps}	; Store address of first block in last element of free lists
(11)	ADDI r_{flps} 1	; Index to end of free lists
(12)	SUBI r_{flps} s	; Index to beginning of free lists
(13)	XOR r_{sp} r_{hp}	; Initialize stack pointer
(14)	ADDI r_{sp} $offset_{stack}$	; Initialize stack pointer
(15)	SUBI r_{sp} $size_m$	; Allocate space for main object
(16)	XOR r_m r_{sp}	; Store address of main object in r_m
(17)	XORI r_v $label_{vt}$	; Store address of vtable in r_v
(18)	PUSH r_v	; Push address of vtable onto stack
(19)	PUSH r_m	; Push 'this' onto stack
(20)	BRA $label_m$	; Call main procedure
(21)	POP r_m	; Pop 'this' from stack
(22)	POP r_v	; Pop vtable address into r_v
(23)	XORI r_v $label_{vt}$	; Clear r_v
(24)	XOR r_m r_{sp}	; Clear r_m
(25)	ADDI r_{sp} $size_m$	; Deallocate space of main object
(26)	SUBI r_{sp} $offset_{stack}$	; Clear stack pointer
(27)	XOR r_{sp} r_{hp}	; Clear stack pointer
(28)	<i>finish</i> : FINISH	; Program exit point

Figure 4.5: Overall layout of a translated ROOPL++ program

The following PISA code block initializes the free lists pointer, the heap pointer, the stack pointer, allocates the main object on the stack, calls the main method, deallocates the main object and finally clears the free lists, heap and stack pointers.

The free lists pointer is initialized by adding the base address, which varies with the size of the translated program, to the register r_{flps} . In figure 4.5 the base address is denoted by p .

The heap pointer is initialized directly after the free lists pointer by adding the size of the free lists. One free list is the size of one word and the full size of the free lists is configured in the source code (defaulted to 10, as described earlier).

Once the heap pointer and free lists pointer is initialized, the initial block of free memory is placed in the largest free lists by indexing to said list, by adding the length of the list of free lists, subtracting 1, writing the address of the first block (which is the same address as the heap

pointer, which points to the beginning of the heap) to the last free list and then resetting the free lists pointer to point to the first list again, afterwards.

The stack pointer is initialized simply by adding the stack offset to the heap pointer register r_{hp} . The stack offset is configured in the source code and defaults to 1024, as described earlier in this chapter. As such, the heap and the stack each have 1024 words of space to utilize. Once the stack pointer has been initialized, the main object is allocated on the stack and the main method called, analogously to the ROOPL program structure.

When the program terminates and the main method returns, the main object is popped from the stack and deallocated and the stack pointer is cleared. The heap and free list pointer not intentionally not cleared to simulate future program simulation using these pointers. The contents of the free lists and whatever is left on the heap is untouched at this point. It is the programmers responsibility to free dynamically allocated objects in their ROOPL++ program. Furthermore, depending on the deallocation order, we might not end up with exactly one fully merged block in the end and as such, we do not invert the steps taken to initialize this initial free memory block. Analogously to ROOPL, the values of the main object are left in the stack section of memory.

4.5 Buddy Memory Translation

As briefly mentioned in section 4.2, the Buddy Memory layout was selected as the memory manager layout as it addressed a number of problems related to fragmentation and initialization. The Buddy Memory layout could be converted to a reversible section with only a few restrictions and side effects, which will be described in this section. Firstly, we present the algorithm translated to PISA. As the algorithm is quite lengthy, it will be broken down into smaller chunks. The full translation is shown in appendix A.

The Buddy Memory algorithm consists of three JANUS procedures; the entry point **malloc**, the recursion body **malloc1** and a helper function **double**. The entry point is omitted for now, as it differs depending on which type of memory object we are allocating and will be presented in sections 4.6 and 4.8.1. The helper function can be implemented using a single instruction in PISA for our specific case of doubling number in the power-of-two, which we will show later.

(1)	$malloc1_{top}$:	BRA	$malloc1_{bot}$	; Receive jump
(2)		POP	r_{ro}	; Pop return offset from the stack
(3)		.....		; Inverse of (7)
(4)	$malloc1_{entry}$:	SWAPBR	r_{ro}	; Malloc1 entry and exit point
(5)		NEG	r_{ro}	; Negate return offset
(6)		PUSH	r_{ro}	; Store return offset on stack
(7-63)		.....		; Allocation code
(64)	$malloc1_{bot}$:	BRA	$malloc1_{top}$	; Jump

Figure 4.6: Dynamic dispatch approach for entering the allocation subroutine

Before we go into depth with the translation of the algorithm, we consider the mechanism for triggering the allocation subroutine. Naively, we could generate the entire block of code required

for allocation for every **new** or **delete** statement in the target program. This approach would severely limit the amount of objects we could allocate as the register pressure of the Buddy Memory implementation is quite high, as we be shown in this section. Instead, we can utilize the dynamic dispatching technique, which also is used for method invocations. This way, we only generate the allocation instructions once, and then simply jump to the entry point from different locations in the program. Figure 4.6 outlines the structure for this approach. By using the **SWAPBR** instruction we can jump from multiple points of origin in the compiled program and internally for the recursive needs of the algorithm itself.

	(7)	.....	; Code for $r_{fl} \leftarrow \text{addr}(fl[c])$
	(8)	.....	; Code for $r_{block} \leftarrow \llbracket fl[c] \rrbracket$
	(9)	.....	; Code for $r_{e1_o} \leftarrow \llbracket c_{size} < object_{size} \rrbracket$
	(10)	XOR r_t r_{e1_o}	; Copy value of $c_{size} < object_{size}$ into r_t
	(11)	.....	; Inverse of (9)
	(12)	$o_{test} :$ BEQ r_t r_0 o_{test_f}	; Receive jump
	(13)	XORI r_t 1	; Clear r_t
	(14-21)	.....	; Code for outer if-then statement
	(22)	XORI r_t 1	; Set $r_t = 1$
	(23)	$o_{assert_t} :$ BRA o_{assert}	; Jump
	(24)	$o_{test_f} :$ BRA o_{test}	; Receive jump
	(25)	.....	; Code for $r_{e1_i} \leftarrow \llbracket \text{addr}(fl[c]) \neq 0 \rrbracket$
	(26)	XOR r_{t2} r_{e1_i}	; Copy value of r_{e1_i} into r_{t2}
	(27)	.....	; Inverse of (25)
	(28)	$i_{test} :$ BEQ r_{t2} r_0 i_{test_f}	; Receive jump
	(29)	XORI r_{t2} 1	; Clear r_{t2}
	(30-34)	.....	; Code for inner if-then statement
	(35)	XORI r_{t2} 1	; Set $r_{t2} = 1$
	(36)	$i_{assert_t} :$ BRA i_{assert}	; Jump
	(37)	$i_{test_f} :$ BRA i_{test}	; Receive jump
	(38-47)	.....	; Code for inner else statement
	(48)	$i_{assert} :$ BNE r_{t2} r_0 i_{assert_t}	; Receive jump
	(49)	EXCH $r_{tmp} r_{fl}$	; Load address of head of current free list
	(50)	SUB r_p r_{cs}	; Set p to previous block address
	(51)	.....	; $r_{e2_{i1}} \leftarrow \llbracket p - c_{size} \neq \text{addr}(fl[c]) \rrbracket$
	(52)	.....	; $r_{e2_{i2}} \leftarrow \llbracket \text{addr}(fl[c]) = 0 \rrbracket$
	(53)	.....	; $r_{e2_{i3}} \leftarrow \llbracket (p - c_{size} \neq \text{addr}(fl[c])) \vee (\text{addr}(fl[c]) = 0) \rrbracket$
	(54)	XOR r_{r2} $r_{e2_{i3}}$	; Copy value of $r_{e2_{i3}}$ into r_{r2}
	(55)	.....	; Inverse of (53)
	(56)	.....	; Inverse of (52)
	(57)	.....	; Inverse of (51)
	(58)	ADD r_p r_{cs}	; Inverse of (50)
	(59)	EXCH $r_{tmp} r_{fl}$	; Inverse of (49)
	(60)	$o_{assert} :$ BNE r_t r_0 o_{assert_t}	; Receive jump
	(61)	.....	; Code for $r_{e2_o} \leftarrow \llbracket c_{size} < object_{size} \rrbracket$
	(62)	XOR r_t r_{e2_o}	; Copy value of $c_{size} < object_{size}$ into r_t
	(63)	.....	; Inverse of (61)


```

1 if (csize < osize) then
2   // outer if-then
3 else
4   if freelists[counter] != 0 then
5     // inner if-then
6   else
7     // inner else
8     fi (freelists[counter] = 0 ||
9       p - csize != freelists[counter])
10 fi csize < osize

```

Figure 4.7: PISA translation of the nested conditionals in the Buddy Memory algorithm

The main recursion body of the algorithm, **malloc1** from listing 3.3, page 56 consists of two conditionals, in which one is nested in the else branch of the outer conditional. Figure 4.7 shows the translation structure of the nested conditional pair, using the translation techniques for conditionals presented in [1].

The nested conditionals contain large amounts of boilerplate code for evaluating the various expressions of the conditionals. As these conditionals requires comparisons with contents of the free lists, we must be careful with extracting and storing the values in the free list.

We have three statements to translate from here. The outer **if-then** statement, the inner **if-then** statement and the inner **else** statement.

1 counter += 1	(14) ADDI r_c 1	; Counter++
2 call double(csize)	(15) RL r_{sc} 1	; Call <i>double</i> (csize)
3 call malloc1(p, osize, freelists,	(16)	; Inverse of (7)
4 counter, csize)	(17)	; Code for pushing temp reg values to stack
5 uncall double(csize)	(18) BRA <i>malloc1_entry</i>	; Call <i>malloc1</i> ()
6 counter -= 1	(19)	; Inverse of (17)
	(20) RR r_{sc} 1	; Inverse of (15)
	(21) SUBI r_c 1	; Inverse of (14)

Figure 4.8: PISA translation of the outer **if-then** statement for the Buddy Memory algorithm

Figure 4.8 shows the translation of the outer **if-then** statement. As briefly mentioned, we can utilize the right bit shift instruction of PISA, **RL**, in place of the **double** helper procedure from the JANUS implementation. By using a simple bit shift, we are able to maintain reversibility elegantly when doubling or halving numbers in the power-of-two. This statement also contains one of the careful storage operations of the free list values, in instruction (16). Before we recursively branch to the entry point, we must place the previously extracted address of the head of the free list back into the free list. This is also the reason for instruction (3) in figure 4.6. Furthermore, we must push all temporary evaluated expression values to the stack, so they can be popped when we return.

1 p += freelists[counter]	(30) ADD r_p r_{block}	; Copy address of the current block to p
2 freelists[counter] -= p	(31) SUB r_{block} r_p	; Clear r_{block}
3	(32) EXCH r_{tmp} r_p	; Load address of next block
4 // Swap head of free list	(33) EXCH r_{tmp} r_{fl}	; Set address of next block as new head of free list
5 // with p's next block	(34) XOR r_{tmp} r_p	; Clear address of next block
6 freelists[counter] ^= M(p)		
7 M(p) ^= freelists[counter]		
8 freelists[counter] ^= M(p)		

Figure 4.9: PISA translation of the inner **if-then** statement for the Buddy Memory algorithm

Figure 4.9 shows the translation of the inner **if-then** statement. This statement translates easily using the **EXCH** instructions to swap with memory locations as simulated in the JANUS code.

1 counter += 1	(38) ADDI r_c 1	; Counter++
2 call double(csize)	(39) RL r_{sc} 1	; Call <i>double</i> (csize)
3 call malloc1(p, osize, freelists,	(40)	; Push temp reg values to stack
4 counter, csize)	(41) BRA <i>malloc1_entry</i>	; Call <i>malloc1</i> ()
5 uncall double(csize)	(42)	; Inverse of (40)
6 counter -= 1	(43) RR r_{sc} 1	; Inverse of (39)
7 freelists[counter] += p	(44) SUBI r_c 1	; Inverse of (38)
8 p += csize	(45) XOR r_{tmp} r_p	; Copy current address of p
	(46) EXCH r_{tmp} r_{fl}	; Store address of p in free list
	(47) ADD r_p r_{cs}	; Split block by p = other half of block

Figure 4.10: PISA translation of the inner **else** statement for the Buddy Memory algorithm

The last statement translation is the inner **else** statement shown in figure 4.10. This statement is almost identical to the outer **if-then** with the addition of the block splitting code. The block

splitting is done in three instructions. First, the current block we are examining is set as the new head of the current free list. Afterwards the current free list block size is added to our pointer p , resulting in an effectively split block.

During the design of the reversible Buddy Memory algorithm limitations on the merging and splitting conditions were required to ensure reversibility. Since a split block is always added to an empty free list, we can only merge adjacent blocks if they are the only two blocks in a free list. In the irreversible Buddy Memory algorithm block merging can occur in any place of the free list, but in the reversible version, we can only merge blocks at the start of the free list to maintain reversibility. The effect of this limitation prevents us from returning to one final block of free memory, if the deallocation order is not exactly opposite of the allocation order.

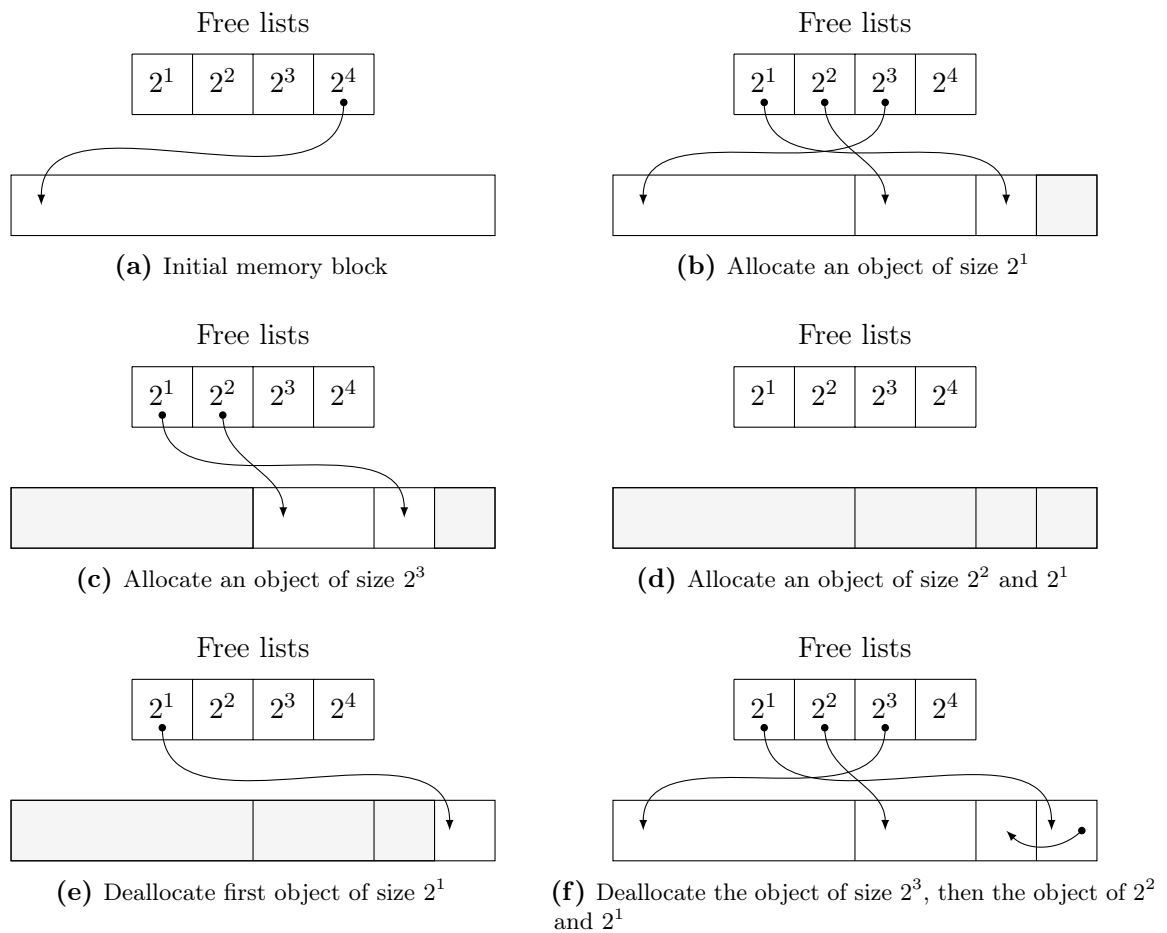


Figure 4.11: Non-opposite deallocation results in a different free list after termination

Figure 4.11 shows how alternative deallocation orders results in different free lists, compared to the original given to some function. However, as discussed in section 3.2, we can consider every collection of Buddy Memory free lists equivalent, as a later computation can take another set of free lists and still execute its function, as long as the free lists have the required blocks available.

4.6 Object Allocation and Deallocation

Now that we have the main allocation mechanism in place and a method of accessing it through a label and a **SWAPBR** instruction, we can continue translating the **malloc** procedure entry point from listing 3.3 on page 56.

	(1)	l_{malloc_top} :	BRA	l_{malloc_bot}	; Receive jump
	(2)	l_{malloc} :	SWAPBR	r_o	; Entry and exit point
	(3)		NEG	r_o	; Negate return offset
1	procedure	malloc (int p, int osize,	(4)	ADDI	c_{size} 2 ; Init c_{size}
2		int freelists[])	(5)	XOR	$r_{counter}$ r_0 ; Init counter
3	local int	counter = 0	(6)	...	; Pop r_p and $object_{size}$ from stack
4	local int	csize = 2	(7)	PUSH	r_0 ; Push r_o
5	call	malloc1(p, osize, freelists,	(8)	BRA	$l_{malloc1}$; call malloc1 ()
6		counter, csize)	(9)	POP	r_0 ; Inverse of (7)
7	delocal int	csize = 2	(10)	...	r_0 ; Inverse of (6)
8	delocal int	counter = 0	(11)	XOR	$r_{counter}$ r_0 ; Inverse of (5)
	(12)		SUBI	c_{size} 2 ; Inverse of (4)	
	(13)	l_{malloc_bot} :	BRA	l_{malloc_top}	; Jump

Figure 4.12: PISA translation of the **malloc** procedure entry point of Buddy Memory algorithm

Figure 4.12 shows the translated **malloc** procedure. In addition to the original procedure, we also push the current return offset register value to the stack before we branch to the **malloc1** implementation, to ensure we have a zero-cleared register before starting the allocation process. The translated procedure assumes that the pointer to the object we are allocating and its size are on top of the stack before entering the block. This translated procedure serves as the entry point for the allocation subroutine as it is also only generated once. Each **new** and **delete** statement branches to the l_{malloc} label to begin an allocation or a deallocation.

new $c\ x$			delete $c\ x$		
(1)	...	; Push registers	(1)	...	; Code for $r_p \leftarrow \llbracket addr(x) \rrbracket$
(2)	...	; Code for $r_t \leftarrow x_{size}$	(2)	EXCH r_t r_p	; extract vtable from object
(3)	PUSH r_t	; Push r_t	(3)	XORI r_t $label_{vt}$	; clear address of vtable in r_t
(4)	PUSH r_p	; Push r_p	(4)	ADDI r_p $offset_{ref}$	; Index to ref count pos
(5)	BRA l_{malloc}	; Allocate	(5)	EXCH r_t r_p	; Extract ref count
(6)	POP r_p	; Inverse of (4)	(6)	XORI r_t 1	; Clear ref count
(7)	POP r_t	; Inverse of (3)	(7)	SUBI r_p $offset_{ref}$	; Inverse of (4)
(8)	...	; Inverse of (2)	(8)	...	; Push registers except r_p , r_t
(9)	...	; Inverse of (1)	(9)	...	; Code for $r_t \leftarrow x_{size}$
(10)	...	; Code for $r_v \leftarrow \llbracket addr(x) \rrbracket$	(10)	PUSH r_t	; Push r_t
(11)	XORI r_t $label_{vt}$	; Store address of vtable in r_t	(11)	PUSH r_p	; Push r_p
(12)	EXCH r_t r_p	; Store vtable in new object	(12)	RBRA l_{malloc}	; Deallocate
(13)	ADDI r_p $offset_{ref}$	; Index to ref count pos	(13)	POP r_p	; Inverse of (11)
(14)	XORI r_t 1	; Init ref count	(14)	POP r_t	; Inverse of (10)
(15)	EXCH r_t r_p	; Store ref count	(15)	...	; Inverse of (9)
(16)	SUBI r_p $offset_{ref}$	; Inverse of (13)	(16)	...	; Inverse of (8)
(17)	EXCH r_p r_v	; Store address in variable	(17)	...	; Inverse of (1)
(18)	...	; Inverse of (10)			

Figure 4.13: PISA translation of heap allocation and deallocation for objects

Figure 4.13 shows how each **new** and **delete** statement for objects are translated during compilation. They are simply inverse of each other. For allocation, the object pointer and its size are pushed to the stack and then a jump to the malloc entry point is executed. After allocation, the virtual table and reference count are stored in the first two words of the allocated memory. Note how deallocation jumps and flips the direction of execution using the **RBRA** instruction, which then runs the allocation process in reverse. In the figure x_{size} denotes the computed size of objects with class c , plus two, to account for the virtual table pointer and reference count space, rounded up to nearest power-of-two.

construct $c\ x\ s\ \text{destruct}\ x$

- (1) **XOR** $r_x\ r_{sp}$; Store address of new object x in r_x
- (2) **PUSH** r_x ; Push r_x to the stack
- (3) ; Code for **new** $c\ x$
- (4) ; Code for statement s
- (5) ; Code for **delete** $c\ x$
- (6) **POP** r_x ; Pop r_x from the stack
- (7) **XOR** $r_x\ r_{sp}$; Clear r_x

Figure 4.14: PISA translation of a ROOPL++ object block

Figure 4.14 shows the updated translation technique for object blocks. In ROOPL, the object blocks allocated their objects on the stack, but in ROOPL++, we can now allocate them on the heap. to facilitate this, we simply execute the exact same instructions as in **new** and **delete** statements, with body statement execution code in between. As described in section 2.6, the **construct**/**desctruct** block can be considered syntactic sugar, and its usage in a real world example would probably be limited.

4.7 Referencing

As mentioned, one of the main strengths of ROOPL++ in terms of increased expressiveness is allowance of multiple references to objects and arrays. When an object or array is constructed we allocate enough space to hold an additional *reference counter* which is initialized to 1. For each reference copied using the **copy**-statement, we incrementally increase the reference counter by one. When we **uncopy** a reference, the reference counter is decreased by one. The object or array cannot be deconstructed until its reference counter has been returned to 1 as we would have a reference pointer to cleared memory in the heap. Such references are known as dangling pointers.

Figure 4.15 shows the object layout of ROOPL++ objects with the added space for the reference counting from the original ROOPL model in figure 4.2 on page 59.

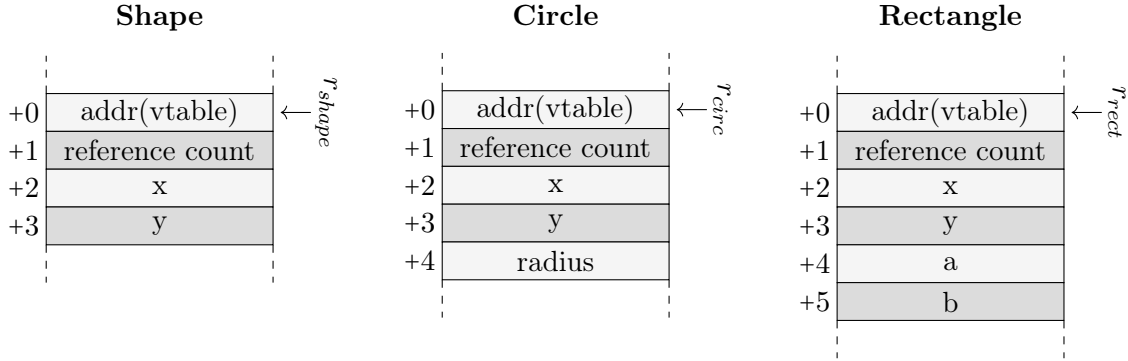


Figure 4.15: Illustration of prefixing in the memory layout of three ROOPL++ objects

Figure 4.16 shows the translated PISA code for the **copy** and **uncopy** statements. As shown, they are both very simple and each others inverse. For copying, the address of the passed variable x is simply copied into the zero-cleared value of x' and the reference count incremented by one. For deletion, the address is cleared and the reference count decremented. Copying and clearing is done through the **XOR** instruction. These translations features no error handling, but a solution is discussed in section 4.9.

copy $c\ x\ x'$		uncopy $c\ x\ x'$	
(1)	... ; Code for $r_p \leftarrow \text{addr}(x)$	(1)	... ; Code for $r_p \leftarrow \text{addr}(x)$
(2)	... ; Code for $r_{cp} \leftarrow \text{value}(x')$	(2)	... ; Code for $r_{cp} \leftarrow \text{value}(x')$
(3)	XOR $r_{cp}\ r_p$; Copy address of x into x'	(3)	XOR $r_{cp}\ r_p$; Clear address of x from x'
(4)	ADDI $r_p\ \text{offset}_{ref}$; Index to reference count address	(4)	ADDI $r_p\ \text{offset}_{ref}$; Index to reference count address
(5)	EXCH $r_t\ r_p$; Extract reference count	(5)	EXCH $r_t\ r_p$; Extract reference count
(6)	ADDI $r_t\ 1$; Increment reference count	(6)	SUBI $r_t\ 1$; Decrement reference count
(7)	EXCH $r_t\ r_p$; Store updated reference count	(7)	EXCH $r_t\ r_p$; Store updated reference count
(8)	SUBI $r_p\ \text{offset}_{ref}$; Inverse of (3)	(8)	SUBI $r_p\ \text{offset}_{ref}$; Inverse of (3)
(9)	... ; Inverse of (2)	(9)	... ; Inverse of (2)
(10)	... ; Inverse of (1)	(10)	... ; Inverse of (1)

Figure 4.16: PISA translation of the reference copying and deletion statements

4.8 Arrays

The fixed-sized arrays in ROOPL++ are also heap allocated to allow dynamic lifetime. The array memory layout is presented in figure 4.17. As shown, the arrays feature two additional fields to store the size of the array and the reference count. Additionally, integer arrays store their values directly in the array, while object arrays are a simple pointer stores.

As the size of a ROOPL++ array is determined by a passed expression evaluation, it is unknown at compile time. This also means that out-of-bounds checking cannot be conducted during compilation. A possible solution for this is presented in section 4.9.

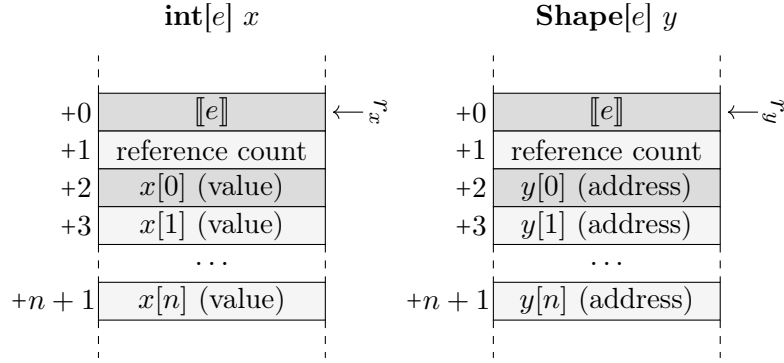


Figure 4.17: Illustration of prefixing in the memory layout of two ROOPL++ arrays

4.8.1 Construction and Destruction

As ROOPL++ arrays also are heap allocated, the buddy allocation implementation is also used for allocating arrays. The only difference between object and array allocation is that no virtual table is stored in the allocated space while the offsets for the reference counter are shared for both types. Due to this fact, **copy** and **uncopy** PISA blocks generated during compile time are exactly the same for arrays and objects, as shown in the previous section.

new $a[e]$ x				delete $a[e]$ x			
(1)	...		; Push registers	(1)	...		; Code for $r_p \leftarrow \llbracket \text{addr}(x) \rrbracket$
(2)	...		; Code for $r_t \leftarrow \llbracket e \rrbracket + 2$	(2)	...		; Code for $r_v \leftarrow \llbracket e \rrbracket$
(3)	PUSH	r_t	; Push r_t	(3)	ADDI	r_p offset_{ref}	; Index to ref count pos
(4)	PUSH	r_p	; Push r_p	(4)	EXCH	r_t r_p	; Extract ref count
(5)	BRA	$l_{m\text{alloc}}$	; Allocate array	(5)	XORI	r_t 1	; Clear ref count
(6)	POP	r_p	; Inverse of (4)	(6)	SUBI	r_p offset_{ref}	; Inverse of (3)
(7)	POP	r_t	; Inverse of (3)	(7)	EXCH	r_t r_p	; extract size from object
(9)	...		; Inverse of (1)	(8)	XORI	r_t r_v	; clear size in r_t
(10)	...		; Code for $r_v \leftarrow \llbracket \text{addr}(x) \rrbracket$	(9)	...		; Push registers except r_p, r_v
(11)	SUBI	r_t 2	; $r_t \leftarrow \llbracket e \rrbracket$	(10)	ADDI	r_v 2	; Actual size of array
(12)	EXCH	r_t r_p	; Store size in new array	(11)	PUSH	r_v	; Push r_v
(13)	ADDI	r_p offset_{ref}	; Index to ref count pos	(12)	PUSH	r_p	; Push r_p
(14)	XORI	r_t 1	; Init ref count	(13)	RBRA	$l_{m\text{alloc}}$	; Deallocate array
(15)	EXCH	r_t r_p	; Store ref count	(14)	POP	r_p	; Inverse of (12)
(16)	SUBI	r_p offset_{ref}	; Inverse of (13)	(15)	POP	r_v	; Inverse of (11)
(17)	EXCH	r_p r_v	; Store address in variable	(16)	SUBI	r_v 2	; Inverse of (10)
(18)	...		; Inverse of (10)	(17)	...		; Inverse of (9)
				(18)	...		; Inverse of (2)
				(19)	...		; Inverse of (1)

Figure 4.18: PISA translations of array allocation and deallocation statements

Figure 4.18 shows the translation schemes used for array allocation and deallocation. As said, these are almost identical to the object allocation and deallocation schemes presented in figure 4.13 on page 66. Classes are analyzed during a compilation phase and their allocation size, the object size + 2 (for virtual table and reference counter) rounded up to nearest power-of-two. The

size of arrays cannot be determined during compilation, as that would require evaluating the expression passed to the initialization call, and as such, we add the overhead needed directly in the allocation and deallocation instructions. While the two blocks of code are not exact opposites they are functionally inverse of each other. An extra **XORI** instruction on line (8) in the deallocation block has been included to clear the stored array size using the value of the passed expression and further use this size for the inverse **malloc** subroutine.

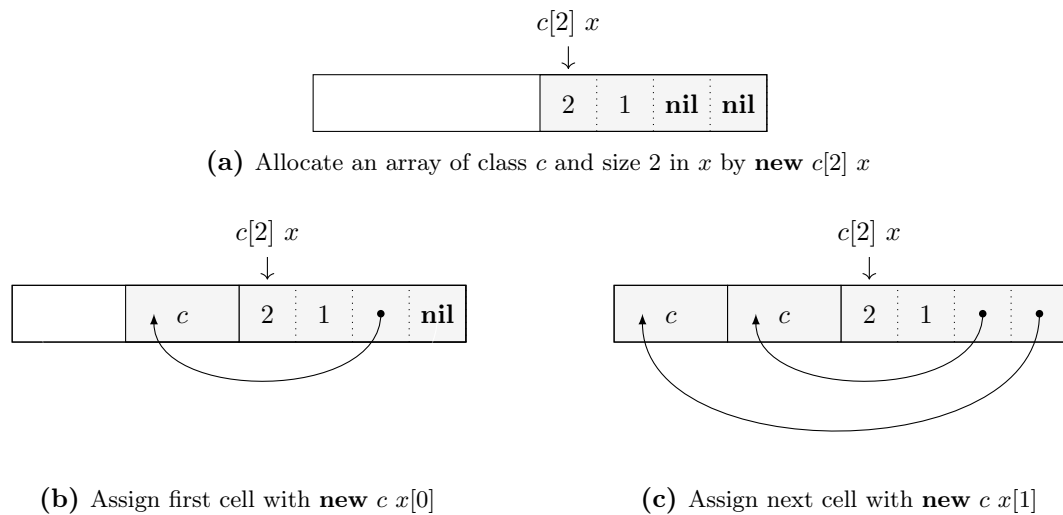


Figure 4.19: Illustration of array memory storage layout

Figure 4.19 shows how object arrays simply contain pointers to allocated objects. For integer arrays, the cell values would be stored directly in the allocated array space instead.

4.8.2 Array Element Access

Array elements are simply passed as any other variable to methods or statements. Based on the variable type, compilation of various statements individually determines whether the address or the value of the passed variable should be used for compiling the statement. For arrays, this is no different. If an integer array element is passed, it is treated just like a regular integer variable. For an object array element, it is treated just like a regular object variable.

4.9 Error Handling

While a program written in ROOPL++ might be syntactically valid and well-typed, this is not a guarantee that it executes successfully. A number of conditions exist, which cannot be determined at compile time, which in turn results in erroneous executed code. Haulund describes the following conditions:

- If the entry expression of a conditional is **true**, then the exit assertion should also be **true** after executing the then-branch.

- If the entry expression of a conditional is **false**, then the exit assertion should also be **false** after executing the else-branch.
- The entry expression of a loop should initially be **true**.
- If the exit assertion of a loop is **false**, then the entry expression should also be **false** after executing the loop-statement.
- All instance variables should be zero-cleared within an object block before the object is deallocated.
- The value of a local variable should always match the value of the delocal-expression after the block statement has executed [11].

The extensions made to ROOPL in ROOPL++ brings forth a number of additional conditions:

- All fields of an object instance should be zero-cleared before the object is deallocated using the **delete** statement.
- All cells of an instance should be zero-cleared before the array is deallocated using the **delete** statement.
- Local object blocks should have their fields zero-cleared after the execution of the block statement.
- Local array blocks should have their cells zero-cleared after the execution of the block statement.
- If the value of a local object variable is exchanged during its block statement and the new value is an object reference, this object must have its fields zero-cleared after the execution of the block statement.
- If the value of a local array variable is exchanged during its block statement and the new value is an array reference, this array must have its cell zero-cleared after the execution of the block statement.
- The variable in the **new** statement must be zero-cleared beforehand.
- The variable in the **copy** statement must be zero-cleared beforehand.
- An object variable must be initialized using **new** or **copy** before its methods can be called.
- An array variable must be initialized using **new** or **copy** before its fields can be accessed.
- Array cell indices must be within bounds defined in the expression passed during initialization.
- Only one reference to an object or an array must exist when executing the **delete** statement.
- Swapping cell values between a subtype A variable and parent-type B array is only allowed if the value stored in the variable is also A afterwards.

It is the programmer's responsibility to meet these conditions. As these conditions, in general, cannot be determined at compile time, undefined program behaviour will occur as the termination will continue silently, resulting in erroneous program state. We can insert run time error checks in the generated instructions such that the program is terminated if one of the conditions does not

hold. The run time error checks can be added as dynamic error checks using error routines defined at labels, such as `labeluninitialized_object` which the program can jump to, if such a condition is unmet. Haulund presented an example for dynamic error checking for local blocks in [11]. PISA and its simulator PendVM is, however, limited and does not support exit codes natively. To fully support dynamic error checking, PendVM could be extended to read from a value from a designated register to supply a more meaningful message for the programmer in the case of a run time exit.

4.10 Implementation

The ROOPL++ compiler (ROOPLPPC) was implemented using techniques and translation schemes presented in this chapter, expanding upon the work of the original ROOPL compiler (ROOPLC). The compiler serves as a proof-of-concept and simply performs one-to-one translations of ROOPL++ code to PISA code without any optimizations along the way. The compiler is written in HASKELL 7.10 and the translated output was tested on the Pendulum simulator, PendVM [5].

As with the ROOPL compiler, the ROOPL++ compiler is structured around the same six separate compilation phases.

1. **Parsing** consists of constructing an abstract syntax tree from the input program text using parser combinators from the PARSEC library in HASKELL.
2. **Class Analysis** verifies inheritance cycles, duplicated method names or fields and base classes. In this phase, we also compute the allocation size of each class
3. **Scope Analysis** constructs the virtual and symbol tables and maps every identifier to a unique variable or method.
4. **Type Checking** verifies that the parsed program is well-typed.
5. **Code Generation** translates the abstract syntax tree to blocks of PISA code in a recursive descent.
6. **Macro Expansion** expands macros left by the code generator for i.e. configuration variables, etc.

Compiled ROOPL programs have a size increase by a factor of 10 to 15 in terms of the lines of code. For ROOPL++ the size increase is much larger, partially due to the increase of static code included in form of the memory manager using the buddy layout described in this chapter and partially because heap allocations are more costly than stack allocations in terms of lines of code.

The ROOPL compiler was implemented in 1403 lines of HASKELL and the ROOPL++ compiler was extended to 2046 lines of HASKELL.

The entire compiler source code as well as example programs and their compiled versions are provided in the appendices and in the supplied ZIP archive. It is also hosted on Github as open source software under the MIT license at <https://github.com/cservenka/ROOPLPPC>.

Building and usage of the compiler is supplied in the README.md file found in the ZIP archive and in appendix B.

4.11 Evaluation

For evaluating the results of the implemented compiler, it was tested against example code provided throughout this thesis. Tests programs utilizing the linked list, doubly-linked list and binary tree data structures and the RTM implementation are found in appendix C.

Program	ROOPL++ LOC	PISA LOC	Number of executed instructions
Linked List	61	1280	18015
Doubly-Linked List	66	1339	21825
Binary Tree	86	2056	6065
RTM Simulation	211	6716	64922

Figure 4.20: Lines of code comparison between target and compiled ROOPL++ programs

The linked list test programs simply instantiates ten cells and links them in their respective lists. The binary tree test program instantiates three nodes and adds them to the tree structure, which afterwards is traversed to determine the sum of the nodes and finally mirroring the tree. The Reversible Turing Machine implementing incrementation of a non-negative n -bit binary number by 1 originally described in [29] has been implemented in ROOPL++ and successfully converts its initial tape value in little endian form of 1101 to 0011 after termination. It should be noted that these test programs require additional stack space during their lengthy computations and as such has been compiled with twice the length between the stack and heap to allow further stack growth.

As discussed, the compiler is considered proof-of-concept and no noteworthy optimizations has been implemented. However, for the sake of giving the reader an idea of the size blowup of a compiled ROOPL++ program, figure 4.20 details this difference. The lines of translated PISA instructions includes the 204 instructions needed for the **malloc** and **malloc1** PISA-equivalent mechanisms. The last row of the table shows how many instructions are execution during simulation using PendVM.

Conclusions

We formally presented a dynamic memory management extension for the reversible object-oriented programming language, ROOPL, in the form of the superset language ROOPL++. The extension expands upon the previously presented static typing system defining well-typedness. The language successfully extends the expressiveness of its predecessor by allowing more flexibility within the domain of reversible object-oriented programming. With ROOPL++ we, as reversible programmers, can now define and model non-trivial dynamic data structures in a reversible setting, such as lists, trees and graphs. We illustrated this by example programs such as a new reversible Turing machine simulator along with implementations for linked lists, doubly-linked lists and binary trees as well as techniques for traversing these. Besides expanding the expressiveness of ROOPL, we have also shown that complex dynamic data structures are not only feasible, but furthermore do not contradict the reversible computing paradigm.

We presented various dynamic memory management layouts and how each would translate into the reversible allocation algorithms. Weighing the advantages and disadvantages of each, the Buddy Memory layout was found to translate into reversible code very naturally with few side effects and addressed a number of disadvantages found in other considered layouts. With dynamically lifetimed objects the allocation and deallocation order is important in terms of a entirely garbage-free computation. In most cases with ROOPL++, we only obtain partially garbage-free computations, as our free lists might not be restored to their original form, without an effective garbage collector design for the memory manager.

Techniques for clean translations of extended parts of the language, such as the memory manager, the new fixed-sized array type and reference counting have been demonstrated and implemented in a proof-of-concept compiler for validation.

With the dynamic memory manager for reversible object-oriented programming languages allowing dynamic object-scopes and multiple references, exemplified by ROOPL++, we have successfully taking an additional step in the direction towards high-level abstractions reversible computations.

5.1 Future Work

Naturally with the discovery of feasibility of non-trivial, reversible data structures with the introduction of ROOPL++, further study of design and implementation of reversible algorithms

working with these data structures are an obvious contender for future research. Data structures such as lists, graphs and trees could potentially provide very interesting future reversible programs.

In terms of the future of reversible object-oriented languages, additional work could be made to extend the fixed-sized array type with a fully dynamic array supporting multiple dimensions. This addition could further help the discovery and research of reversible data structures such as trees and graphs. Such an extension could perhaps be added via a **put** and **take** statement pair, being each others inverse. After a dynamic array has been declared, it could automatically reallocate or upscale its internal space when putting new data outside of its current bounds. In reverse, the space could shrink or reallocate when removing the largest indexed value. The current memory management layout will still suffice for this extension.

Finally, more research could be conducted into reversible heap managers. We provided a simple manager which translated to our problem domain naturally. To obtain completely garbage free computations, a garbage collector could be designed to work with the reversible Buddy Memory memory manager. A reversible garbage collector for non-mutable objects has been designed and shown feasible for the reversible functional language RCFUN in [19]. Additionally, experimentation with implementing the Buddy Memory layout into other reversible languages with dynamic allocation and deallocation such as R-WHILE and R-CORE provides an interesting opportunity [8, 9].

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Pisa Translated Buddy Memory

```

(1)  malloc1_top :  BRA      malloc1_bot      ; Receive jump
(2)                                POP      r_ro      ; Pop return offset from the stack
(3)                                .....      ; Inverse of (7)
(4)  malloc1_entry : SWAPBR   r_ro      ; Malloc1 entry and exit point
(5)                                NEG      r_ro      ; Negate return offset
(6)                                PUSH     r_ro      ; Store return offset on stack
(7)                                .....      ; Code for  $r_{fl} \leftarrow \text{addr}(\text{freelists}[\text{counter}])$ 
(8)                                .....      ; Code for  $r_{block} \leftarrow \llbracket \text{freelists}[\text{counter}] \rrbracket$ 
(9)                                .....      ; Code for  $r_{e1o} \leftarrow \llbracket c_{size} < \text{object}_{size} \rrbracket$ 
(10)                               XOR      r_t      r_e1o      ; Copy value of  $c_{size} < \text{object}_{size}$  into  $r_t$ 
(11)                               .....      ; Inverse of (9)
(12)  o_test :      BEQ      r_t      r_0      o_test_f      ; Receive jump
(13)                                XORI     r_t      1      ; Clear  $r_t$ 
(14)                                ADDI     r_c      1      ; Counter++
(15)                                RL       r_sc      1      ; Call  $\text{double}(c_{size})$ 
(16)                                .....      ; Inverse of (7)
(17)                                .....      ; Code for pushing temp reg values to stack
(18)                                BRA      malloc1_entry      ; Call  $\text{malloc}()$ 
(19)                                .....      ; Inverse of (17)
(20)                                RR       r_sc      1      ; Inverse of (15)
(21)                                SUBI     r_c      1      ; Inverse of (14)
(22)                                XORI     r_t      1      ; Set  $r_t = 1$ 
(23)  o_assert_t :  BRA      o_assert      ; Jump
(24)  o_test_f :    BRA      o_test      ; Receive jump
(25)                                .....      ; Code for  $r_{e1i} \leftarrow \llbracket \text{addr}(\text{freelists}[\text{counter}]) \rrbracket \neq 0$ 
(26)                                XOR      r_t2     r_e1i      ; Copy value of  $r_{e1i}$  into  $r_{t2}$ 
(27)                                .....      ; Inverse of (25)
(28)  i_test :      BEQ      r_t2     r_0      i_test_f      ; Receive jump
(29)                                XORI     r_t2     1      ; Clear  $r_{t2}$ 
(30)                                ADD      r_p      r_block      ; Copy address of the current block to p
(31)                                SUB      r_block   r_p      ; Clear  $r_{block}$ 
(32)                                EXCH     r_tmp     r_p      ; Load address of next block
(33)                                EXCH     r_tmp     r_fl      ; Set address of next block as new head of free list
(34)                                XOR      r_tmp     r_p      ; Clear address of next block
(35)                                XORI     r_t2     1      ; Set  $r_{t2} = 1$ 
(36)  i_assert_t :  BRA      i_assert      ; Jump
(37)  i_test_f :    BRA      i_test      ; Receive jump
(38)                                ADDI     r_c      1      ; Counter++
(39)                                RL       r_sc      1      ; Call  $\text{double}(c_{size})$ 
(40)                                .....      ; Code for pushing temp reg values to stack
(41)                                BRA      malloc1_entry      ; Call  $\text{malloc}()$ 
(42)                                .....      ; Inverse of (40)
(43)                                RR       r_sc      1      ; Inverse of (39)
(44)                                SUBI     r_c      1      ; Inverse of (38)

```


(45)	XOR	r_{tmp}	r_p		; Copy current address of p
(46)	EXCH	r_{tmp}	r_{fl}		; Store current address of p in current free list
(47)	ADD	r_p	r_{cs}		; Split block by setting p to second half of current block
(48) $i_{assert} :$	BNE	r_{t2}	r_0	i_{assert}_t	; Receive jump
(49)	EXCH	r_{tmp}	r_{fl}		; Load address of head of current free list
(50)	SUB	r_p	r_{cs}		; Set p to previous block address
(51)	.....				; Code for $r_{e2_{i1}} \leftarrow \llbracket p - c_{size} \neq \text{addr}(\text{freelists}[\text{counter}]) \rrbracket$
(52)	.....				; Code for $r_{e2_{i2}} \leftarrow \llbracket \text{addr}(\text{freelists}[\text{counter}]) = 0 \rrbracket$
(53)	.....				; Code for $r_{e2_{i3}} \leftarrow \llbracket (p - c_{size} \neq \text{addr}(\text{freelists}[\text{counter}])) \vee (\text{addr}(\text{freelists}[\text{counter}]) = 0) \rrbracket$
(54)	XOR	r_{r2}	$r_{e2_{i3}}$		; Copy value of $r_{e2_{i3}}$ into r_{t2}
(55)	.....				; Inverse of (53)
(56)	.....				; Inverse of (52)
(57)	.....				; Inverse of (51)
(58)	ADD	r_p	r_{cs}		; Inverse of (50)
(59)	EXCH	r_{tmp}	r_{fl}		; Inverse of (49)
(60) $o_{assert} :$	BNE	r_t	r_0	o_{assert}_t	; Receive jump
(61)	.....				; Code for $r_{e2_o} \leftarrow \llbracket c_{size} < \text{object}_{size} \rrbracket$
(62)	XOR	r_t	r_{e2_o}		; Copy value of $c_{size} < \text{object}_{size}$ into r_t
(63)	.....				; Inverse of (61)
(64) $\text{malloc1}_{bot} :$	BRA		malloc1_{top}		; Jump

ROOPLPPC Source Code

README.md

```
1 # ROOPLPPC
2
3 *ROOPLPP* is a compiler translating source code written in **Reversible Object Oriented
  Programming Language+++ (ROOPL++) to the reversible assembly language Pendulum ISA (PISA)
  .
4
5 The compiler is to be considered proof-of-concept in connection with my Master's Thesis on the
  ROOPL++ language.
6
7 ## Requirements
8 ROOPLPPC uses [Stack](https://docs.haskellstack.org/en/stable/README/) to manage all
  dependencies and requirements.
9
10 ## Building
11 Simply invoke
12 ```
13 stack build
14 ```
15 which compiles an executable into the '.stack-work' folder
16
17 ## Usage
18 To compile a ROOPL++ program simply run
19 ```
20 stack exec ROOPLPPC input.rplpp
21 ```
22 which compiles the input program into Pisa and stores the compiled file as 'input.pal' in the
  current directory.
23
24 To specify an output file name, simply provide it as an additional argument
25 ```
26 stack exec ROOPLPP input.rplpp output.pal
27 ```
28
29 ## Examples
30 To see usage examples, please refer to 'test/' for example programs.
31
32 ## Running compiled programs
33 The PendVM simulator executes compiled Pisa code and is hosted on Github [here](https://github
  .com/TueHaulund/PendVM).
```

AST.hs

```
1 module AST where
2
3 import Text.Show.Pretty
4
5 {-# AST Primitives #-}
6 type TypeName = String
7
8 type MethodName = String
9
10 data DataType = IntegerType
11               | ObjectType TypeName
12               | CopyType TypeName
13               | ^ ObjectArrayType TypeName
14               | IntegerArrayType
15               | ArrayType
16               | ArrayElementType
17               | NilType
18
19 deriving (Show)
20
21 -- Types
22 instance Eq DataType where
23   IntegerType == IntegerType = True
24   IntegerArrayType == IntegerArrayType = True
25   NilType == NilType = True
26   NilType == (ObjectType _) = True
27   (ObjectType _) == NilType = True
28   (ObjectType t1) == (ObjectType t2) = t1 == t2
29   (CopyType t1) == (CopyType t2) = t1 == t2
30   (ObjectArrayType t1) == (ObjectArrayType t2) = t1 == t2
31   (CopyType t1) == (ObjectType t2) = t1 == t2
32   (ObjectType t1) == (CopyType t2) = t1 == t2
33   ArrayType == (ObjectArrayType _) = True
34   (ObjectArrayType _) == ArrayType = True
35   ArrayType == IntegerArrayType = True
36   IntegerArrayType == ArrayType = True
37   _ == _ = False
38
39 -- Binary Operators
40 data BinOp = Add
41            | Sub
42            | Xor
43            | Mul
44            | Div
45            | Mod
46            | BitAnd
47            | BitOr
48            | And
49            | Or
50            | Lt
51            | Gt
52            | Eq
53            | Neq
54            | Lte
55            | Gte
56
57 deriving (Show, Eq, Enum)
58
59 data ModOp = ModAdd
60            | ModSub
61            | ModXor
62
63 deriving (Show, Eq, Enum)
64
65 {-# Generic AST Definitions #-}
66 --Expressions
```

```

64 data GExpr v = Constant Integer
65             | Variable v
66             | ArrayElement (v, GExpr v)
67             | Nil
68             | Binary BinOp (GExpr v) (GExpr v)
69 deriving (Show, Eq)
70
71 --Statements
72 data GStmt m v = Assign v ModOp (GExpr v)
73               | AssignArrElem (v, GExpr v) ModOp (GExpr v)
74               | Swap (v, Maybe (GExpr v)) (v, Maybe (GExpr v))
75               | Conditional (GExpr v) [GStmt m v] [GStmt m v] (GExpr v)
76               | Loop (GExpr v) [GStmt m v] [GStmt m v] (GExpr v)
77               | ObjectBlock TypeName v [GStmt m v]
78               | LocalBlock DataType v (GExpr v) [GStmt m v] (GExpr v)
79               | LocalCall m [(v, Maybe (GExpr v))]
80               | LocalUncall m [(v, Maybe (GExpr v))]
81               | ObjectCall (v, Maybe (GExpr v)) MethodName [(v, Maybe (GExpr v))]
82               | ObjectUncall (v, Maybe (GExpr v)) MethodName [(v, Maybe (GExpr v))]
83               | ObjectConstruction TypeName (v, Maybe (GExpr v))
84               | ObjectDestruction TypeName (v, Maybe (GExpr v))
85               | CopyReference DataType (v, Maybe (GExpr v)) (v, Maybe (GExpr v))
86               | UnCopyReference DataType (v, Maybe (GExpr v)) (v, Maybe (GExpr v))
87               | ArrayConstruction (TypeName, GExpr v) v
88               | ArrayDestruction (TypeName, GExpr v) v
89               | Skip
90 deriving (Show, Eq)
91
92 --Field/Parameter declarations
93 data GDecl v = GDecl DataType v
94 deriving (Show, Eq)
95
96 --Method: Name, parameters, body
97 data GMDecl m v = GMDecl m [GDecl v] [GStmt m v]
98 deriving (Show, Eq)
99
100 --Class: Name, fields, methods
101 data GCDecl m v = GCDecl TypeName (Maybe TypeName) [GDecl v] [GMDecl m v]
102 deriving (Show, Eq)
103
104 --Program
105 newtype GProg m v = GProg [GCDecl m v]
106 deriving (Show, Eq)
107
108 {- Specific AST Definitions -}
109 --Plain AST
110 type Identifier = String
111
112 type Expression = GExpr Identifier
113
114 type Statement = GStmt MethodName Identifier
115
116 type VariableDeclaration = GDecl Identifier
117
118 type MethodDeclaration = GMDecl MethodName Identifier
119
120 type ClassDeclaration = GCDecl MethodName Identifier
121
122 type Program = GProg MethodName Identifier
123
124 --Scoped AST
125 type SIdentifier = Integer
126
127 type SExpression = GExpr SIdentifier
128
129 type SStatement = GStmt SIdentifier SIdentifier

```

```

130
131 type SVariableDeclaration = GDecl SIdentifier
132
133 type SMethodDeclaration = GMDecl SIdentifier SIdentifier
134
135 type SProgram = [(TypeName, GMDecl SIdentifier SIdentifier)]
136
137 {-- Other Definitions --}
138 type Offset = Integer
139
140 data Symbol = LocalVariable DataType Identifier
141             | ClassField DataType Identifier TypeName Offset
142             | MethodParameter DataType Identifier
143             | Method [DataType] MethodName
144   deriving (Show, Eq)
145
146 type SymbolTable = [(SIdentifier, Symbol)]
147
148 type Scope = [(Identifier, SIdentifier)]
149
150 printAST :: (Show t) => t -> String
151 printAST = ppShow

```

PISA.hs

```
1 {-# LANGUAGE FlexibleInstances, TypeSynonymInstances #-}
2
3 module PISA where
4
5 import Data.List (intercalate)
6 import Control.Arrow
7
8 import AST (TypeName, MethodName)
9
10 type Label = String
11
12 newtype Register = Reg Integer
13     deriving (Eq)
14
15 {-# Generic PISA Definitions -#}
16
17 data GInstr i = ADD Register Register
18               | ADDI Register i
19               | ANDX Register Register Register
20               | ANDIX Register Register i
21               | NORX Register Register Register
22               | NEG Register
23               | ORX Register Register Register
24               | ORIX Register Register i
25               | RL Register i
26               | RLV Register Register
27               | RR Register i
28               | RRV Register Register
29               | SLIX Register Register i
30               | SLLVX Register Register Register
31               | SRAX Register Register i
32               | SRAVX Register Register Register
33               | SRLX Register Register i
34               | SRLVX Register Register Register
35               | SUB Register Register
36               | XOR Register Register
37               | XORI Register i
38               | BEQ Register Register Label
39               | BGEZ Register Label
40               | BGTZ Register Label
41               | BLEZ Register Label
42               | BLTZ Register Label
43               | BNE Register Register Label
44               | BRA Label
45               | EXCH Register Register
46               | SWAPBR Register
47               | RBRA Label
48               | START
49               | FINISH
50               | DATA i
51               | SUBI Register i --Pseudo
52     deriving (Eq)
53
54 newtype GProg i = GProg [(Maybe Label, GInstr i)]
55
56 {-# Macro PISA Definitions -#}
57
58 data Macro = Immediate Integer
59             | AddressMacro Label
60             | SizeMacro TypeName
61             | OffsetMacro TypeName MethodName
62             | ProgramSize
63             | FreeListsSize
```

```

64         | StackOffset
65         | InitialMemoryBlockSize
66         | ReferenceCounterIndex
67         | ArrayElementOffset
68     deriving (Show, Eq)
69
70 type MInstruction = GInstr Macro
71 type MProgram = GProg Macro
72
73 invertInstructions :: [(Maybe Label, MInstruction)] -> [(Maybe Label, MInstruction)]
74 invertInstructions = reverse . map (second invertInstruction . first (fmap (++ "_i")))
75     where invertInstruction (ADD r1 r2) = SUB r1 r2
76           invertInstruction (SUB r1 r2) = ADD r1 r2
77           invertInstruction (ADDI r i) = SUBI r i
78           invertInstruction (SUBI r i) = ADDI r i
79           invertInstruction (RL r i) = RR r i
80           invertInstruction (RLV r1 r2) = RRV r1 r2
81           invertInstruction (RR r i) = RL r i
82           invertInstruction (RRV r1 r2) = RLV r1 r2
83           invertInstruction (BEQ r1 r2 l) = BEQ r1 r2 $ l ++ "_i"
84           invertInstruction (BGEZ r l) = BGEZ r $ l ++ "_i"
85           invertInstruction (BGTZ r l) = BGTZ r $ l ++ "_i"
86           invertInstruction (BLEZ r l) = BLEZ r $ l ++ "_i"
87           invertInstruction (BLTZ r l) = BLTZ r $ l ++ "_i"
88           invertInstruction (BNE r1 r2 l) = BNE r1 r2 $ l ++ "_i"
89           invertInstruction (BRA l) = BRA $ l ++ "_i"
90           invertInstruction (RBRA l) = RBRA $ l ++ "_i"
91           invertInstruction inst = inst
92
93 {-# Output PISA Definitions -#}
94
95 type Instruction = GInstr Integer
96 type Program = GProg Integer
97
98 instance Show Register where
99     show (Reg r) = "$" ++ show r
100
101 instance Show Instruction where
102     show (ADD r1 r2) = unwords ["ADD ", show r1, show r2]
103     show (ADDI r i) = unwords ["ADDI ", show r, show i]
104     show (ANDX r1 r2 r3) = unwords ["ANDX ", show r1, show r2, show r3]
105     show (ANDIX r1 r2 i) = unwords ["ANDIX ", show r1, show r2, show i]
106     show (NORX r1 r2 r3) = unwords ["NORX ", show r1, show r2, show r3]
107     show (NEG r) = unwords ["NEG ", show r]
108     show (ORX r1 r2 r3) = unwords ["ORX ", show r1, show r2, show r3]
109     show (ORIX r1 r2 i) = unwords ["ORIX ", show r1, show r2, show i]
110     show (RL r i) = unwords ["RL ", show r, show i]
111     show (RLV r1 r2) = unwords ["RLV ", show r1, show r2]
112     show (RR r i) = unwords ["RR ", show r, show i]
113     show (RRV r1 r2) = unwords ["RRV ", show r1, show r2]
114     show (SLLX r1 r2 i) = unwords ["SLLX ", show r1, show r2, show i]
115     show (SLLVX r1 r2 r3) = unwords ["SLLVX ", show r1, show r2, show r3]
116     show (SRAX r1 r2 i) = unwords ["SRAX ", show r1, show r2, show i]
117     show (SRAVX r1 r2 r3) = unwords ["SRAVX ", show r1, show r2, show r3]
118     show (SRLX r1 r2 i) = unwords ["SRLX ", show r1, show r2, show i]
119     show (SRLVX r1 r2 r3) = unwords ["SRLVX ", show r1, show r2, show r3]
120     show (SUB r1 r2) = unwords ["SUB ", show r1, show r2]
121     show (XOR r1 r2) = unwords ["XOR ", show r1, show r2]
122     show (XORI r i) = unwords ["XORI ", show r, show i]
123     show (BEQ r1 r2 l) = unwords ["BEQ ", show r1, show r2, l]
124     show (BGEZ r l) = unwords ["BGEZ ", show r, l]
125     show (BGTZ r l) = unwords ["BGTZ ", show r, l]
126     show (BLEZ r l) = unwords ["BLEZ ", show r, l]
127     show (BLTZ r l) = unwords ["BLTZ ", show r, l]
128     show (BNE r1 r2 l) = unwords ["BNE ", show r1, show r2, l]
129     show (BRA l) = unwords ["BRA ", l]

```

```

130     show (EXCH r1 r2) = unwords ["EXCH ", show r1, show r2]
131     show (SWAPBR r) = unwords ["SWAPBR", show r]
132     show (RBRA l) = unwords ["RBRA ", l]
133     show START = "START "
134     show FINISH = "FINISH"
135     show (DATA i) = unwords ["DATA ", show i]
136     show (SUBI r i) = unwords ["ADDI ", show r, show $ -i] --Expand pseudo
137
138 showProgram :: Program -> String
139 showProgram (GProg p) = ";; pendulum pal file\n" ++ intercalate "\n" (map showLine p)
140     where showLine (Nothing, i) = spaces 25 ++ show i
141           showLine (Just l, i) = l ++ ":" ++ spaces (24 - length l) ++ show i
142           spaces :: (Int -> String)
143           spaces n = [1..n] >> " "
144
145 writeProgram :: String -> Program -> IO ()
146 writeProgram output p = writeFile output $ showProgram p

```

Parser.hs

```
1 module Parser (parseString) where
2
3 import Control.Monad.Except
4 import Data.Functor.Identity
5 import Data.Bifunctor
6
7 import Text.Parsec
8 import Text.Parsec.String
9 import Text.Parsec.Expr
10 import Text.Parsec.Language
11 import qualified Text.Parsec.Token as Token
12
13 import Debug.Trace (trace, traceShow)
14
15 import AST
16
17 {-# Language Definition #-}
18 keywords :: [String]
19 keywords =
20     ["class",
21      "inherits",
22      "method",
23      "call",
24      "uncall",
25      "construct",
26      "destruct",
27      "skip",
28      "from",
29      "do",
30      "loop",
31      "until",
32      "int",
33      "nil",
34      "if",
35      "then",
36      "else",
37      "fi",
38      "local",
39      "delocal",
40      "new",
41      "delete",
42      "copy",
43      "uncopy"]
44
45 --Operator precedence identical to C
46 operatorTable :: [(String, BinOp)]
47 operatorTable =
48     [ ("*", Mul), ("/", Div), ("% ", Mod)],
49     [ ("+", Add), ("-", Sub)],
50     [ ("<", Lt), ("<=", Lte), (">", Gt), (">=", Gte)],
51     [ ("=", Eq), ("!=", Neq)],
52     [("&", BitAnd)],
53     [("^", Xor)],
54     [("|", BitOr)],
55     [("&&", And)],
56     [("||", Or)] ]
57
58 languageDef :: Token.LanguageDef st
59 languageDef =
60     emptyDef {
61         Token.commentLine      = "//",
62         Token.nestedComments   = False,
63         Token.identStart       = letter,
```

```

64     Token.identLetter      = alphaNum <|> oneOf "_'",
65     Token.reservedOpNames = concatMap (map fst) operatorTable,
66     Token.reservedNames   = keywords,
67     Token.caseSensitive   = True }
68
69 tokenParser :: Token.TokenParser st
70 tokenParser = Token.makeTokenParser languageDef
71
72 {-# Parser Primitives #-}
73 identifier :: Parser String
74 identifier = Token.identifier tokenParser
75
76 arrElemIdentifier :: Parser (String, Expression)
77 arrElemIdentifier = do x <- identifier
78                     y <- brackets expression
79                     return (x, y)
80
81 anyIdentifier :: Parser (String, Maybe Expression)
82 anyIdentifier = do x <- identifier
83                 y <- optionMaybe $ brackets expression
84                 return (x, y)
85
86 reserved :: String -> Parser ()
87 reserved = Token.reserved tokenParser
88
89 reservedOp :: String -> Parser ()
90 reservedOp = Token.reservedOp tokenParser
91
92 integer :: Parser Integer
93 integer = Token.integer tokenParser
94
95 symbol :: String -> Parser String
96 symbol = Token.symbol tokenParser
97
98 parens :: Parser a -> Parser a
99 parens = Token.parens tokenParser
100
101 brackets :: Parser a -> Parser a
102 brackets = Token.brackets tokenParser
103
104 colon :: Parser String
105 colon = Token.colon tokenParser
106
107 commaSep :: Parser a -> Parser [a]
108 commaSep = Token.commaSep tokenParser
109
110 typeName :: Parser TypeName
111 typeName = identifier
112
113 arrayTypeName :: Parser (TypeName, Expression)
114 arrayTypeName = do x <- try typeName <|> string "int"
115                 y <- brackets expression
116                 return (x, y)
117
118 methodName :: Parser MethodName
119 methodName = identifier
120
121 {-# Expression Parsers #-}
122 constant :: Parser Expression
123 constant = Constant <$> integer
124
125 variable :: Parser Expression
126 variable = Variable <$> identifier
127
128 arrayElementVariable :: Parser Expression
129 arrayElementVariable = ArrayElement <$> arrElemIdentifier

```

```

130
131 nil :: Parser Expression
132 nil = Nil <$ reserved "nil"
133
134 expression :: Parser Expression
135 expression = buildExpressionParser opTable $ constant <|> try arrayElementVariable <|>
    variable <|> nil
136     where binop (t, op) = Infix (Binary op <$ reservedOp t) AssocLeft
137         opTable = (map . map) binop operatorTable
138
139 -- Statement Parsers --
140 modOp :: Parser ModOp
141 modOp = ModAdd <$ symbol "+="
142     <|> ModSub <$ symbol "-="
143     <|> ModXor <$ symbol "^="
144
145 assign :: Parser Statement
146 assign = Assign <$> identifier <*> modOp <*> expression
147
148 assignArrElem :: Parser Statement
149 assignArrElem = AssignArrElem <$> arrElemIdentifier <*> modOp <*> expression
150
151 swap :: Parser Statement
152 swap = Swap <$> anyIdentifier <* symbol "<=>" <*> anyIdentifier
153
154 conditional :: Parser Statement
155 conditional =
156     reserved "if"
157     >> Conditional
158     <$> expression
159     <*> reserved "then"
160     <*> block
161     <*> reserved "else"
162     <*> block
163     <*> reserved "fi"
164     <*> expression
165
166 loop :: Parser Statement
167 loop =
168     reserved "from"
169     >> Loop
170     <$> expression
171     <*> reserved "do"
172     <*> block
173     <*> reserved "loop"
174     <*> block
175     <*> reserved "until"
176     <*> expression
177
178 localCall :: Parser Statement
179 localCall =
180     reserved "call"
181     >> LocalCall
182     <$> methodName
183     <*> parens (commaSep anyIdentifier)
184
185 localUncall :: Parser Statement
186 localUncall =
187     reserved "uncall"
188     >> LocalUncall
189     <$> methodName
190     <*> parens (commaSep anyIdentifier)
191
192 objectCall :: Parser Statement
193 objectCall =
194     reserved "call"

```

```

195     >> ObjectCall
196     <$> anyIdentifier
197     <*> colon
198     <*> colon
199     <*> methodName
200     <*> parens (commaSep anyIdentifier)
201
202 objectUncall :: Parser Statement
203 objectUncall =
204     reserved "uncall"
205     >> ObjectUncall
206     <$> anyIdentifier
207     <*> colon
208     <*> colon
209     <*> methodName
210     <*> parens (commaSep anyIdentifier)
211
212 objectConstruction :: Parser Statement
213 objectConstruction =
214     reserved "new"
215     >> ObjectConstruction
216     <$> typeName
217     <*> anyIdentifier
218
219 objectDestruction :: Parser Statement
220 objectDestruction =
221     reserved "delete"
222     >> ObjectDestruction
223     <$> typeName
224     <*> anyIdentifier
225
226 localBlock :: Parser Statement
227 localBlock =
228     reserved "local"
229     >> LocalBlock
230     <$> dataType
231     <*> identifier
232     <*> symbol "="
233     <*> expression
234     <*> block
235     <*> reserved "delocal"
236     <*> dataType
237     <*> identifier
238     <*> symbol "="
239     <*> expression
240
241 objectBlock :: Parser Statement
242 objectBlock =
243     reserved "construct"
244     >> ObjectBlock
245     <$> typeName
246     <*> identifier
247     <*> block
248     <*> reserved "destruct"
249     <*> identifier
250
251 skip :: Parser Statement
252 skip = Skip <$> reserved "skip"
253
254 copyReference :: Parser Statement
255 copyReference =
256     reserved "copy"
257     >> CopyReference
258     <$> dataType
259     <*> anyIdentifier
260     <*> anyIdentifier

```

```

261
262 unCopyReference :: Parser Statement
263 unCopyReference =
264     reserved "uncopy"
265     >> UnCopyReference
266     <$> dataType
267     <*> anyIdentifier
268     <*> anyIdentifier
269
270 arrayConstruction :: Parser Statement
271 arrayConstruction =
272     reserved "new"
273     >> ArrayConstruction
274     <$> arrayTypeName
275     <*> identifier
276
277 arrayDestruction :: Parser Statement
278 arrayDestruction =
279     reserved "delete"
280     >> ArrayDestruction
281     <$> arrayTypeName
282     <*> identifier
283
284 statement :: Parser Statement
285 statement = try assign
286     <|> try assignArrElem <|> swap
287     <|> conditional
288     <|> loop
289     <|> try localCall
290     <|> try localUncall
291     <|> objectCall
292     <|> objectUncall
293     <|> localBlock
294     <|> objectBlock
295     <|> try arrayConstruction <|> objectConstruction
296     <|> try arrayDestruction <|> objectDestruction
297     <|> skip
298     <|> copyReference
299     <|> unCopyReference
300
301 block :: Parser [Statement]
302 block = many1 statement
303
304 {-- Top Level Parsers --}
305 dataType :: Parser DataType
306 dataType = try (IntegerArrayType <$ reserved "int" <*> symbol "[" <*> symbol "]")
307     <|> IntegerType <$ reserved "int"
308     <|> try (ObjectArrayType <$> typeName <*> symbol "[" <*> symbol "]")
309     <|> ObjectType <$> typeName
310
311
312 variableDeclaration :: Parser VariableDeclaration
313 variableDeclaration = GDecl <$> dataType <*> identifier
314
315 methodDeclaration :: Parser MethodDeclaration
316 methodDeclaration =
317     reserved "method"
318     >> GMDecl
319     <$> methodName
320     <*> parens (commaSep variableDeclaration)
321     <*> block
322
323 classDeclaration :: Parser ClassDeclaration
324 classDeclaration =
325     reserved "class"
326     >> GCDDecl

```

```
327     <$> typeName
328     <*> optionMaybe (reserved "inherits" >> typeName)
329     <*> many variableDeclaration
330     <*> many1 methodDeclaration
331
332 program :: Parser Program
333 program = spaces >> GProg <$> many1 classDeclaration <*> eof
334
335 parseString :: String -> Except String Program
336 parseString s = ExceptT (Identity $ first show $ parse program "" s)
```

ClassAnalyzer.hs

```
1 {-# LANGUAGE GeneralizedNewtypeDeriving, FlexibleContexts #-}
2
3 module ClassAnalyzer
4   ( classAnalysis
5   , printCAState
6   , CAState(..)
7   ) where
8
9 import Data.List
10 import Data.Maybe
11
12 import Control.Monad
13 import Control.Monad.Except
14 import Control.Monad.State
15 import Text.Pretty.Simple (pPrint)
16
17 import Debug.Trace (trace, traceShow)
18
19 import AST
20
21 type Size = Integer
22
23 -- | The Class Analyzer State consists of a list of classes, sizes, methods
24 -- | and a main class
25 data CAState = CAState {
26   classes :: [(TypeName, ClassDeclaration)],
27   subClasses :: [(TypeName, [TypeName])],
28   superClasses :: [(TypeName, [TypeName])],
29   classSize :: [(TypeName, Size)],
30   classMethods :: [(TypeName, [MethodDeclaration])],
31   mainClass :: Maybe TypeName
32 } deriving (Show, Eq)
33
34 -- | The Class Analyzer monad
35 newtype ClassAnalyzer a = ClassAnalyzer { runCA :: StateT CAState (Except String) a }
36   deriving (Functor, Applicative, Monad, MonadState CAState, MonadError String)
37
38 -- | Initializes the Class Analyzer State with empty lists and Nothing for the mainClass
39 initialState :: CAState
40 initialState = CAState {
41   classes = [],
42   subClasses = [],
43   superClasses = [],
44   classSize = [],
45   classMethods = [],
46   mainClass = Nothing
47 }
48
49 -- | Returns a class from the Class Analyzer State if passed typename matches
50 getClass :: TypeName -> ClassAnalyzer ClassDeclaration
51 getClass n = gets classes >>= \cs ->
52   case lookup n cs of
53     (Just c) -> return c
54     Nothing -> throwError $ "ICE: Unknown class " ++ n
55
56 -- | Returns the base class inherited from
57 getBaseClass :: TypeName -> ClassAnalyzer (Maybe TypeName)
58 getBaseClass n = getClass n >>= getBase
59   where getBase (GCDecl _ b _) = return b
60
61 -- | Throws error if class is defined multiple times
62 checkDuplicateClasses :: ClassDeclaration -> ClassAnalyzer ()
63 checkDuplicateClasses (GCDecl n _ _) = gets classes >>= \cs ->
```

```

64     when (count cs > 1) (throwError $ "Multiple definitions of class " ++ n)
65     where count = length . filter ((== n) . fst)
66
67 -- | Ensures legal inheritance
68 checkBaseClass :: ClassDeclaration -> ClassAnalyzer ()
69 checkBaseClass (GCDDecl _ Nothing _ _) = return ()
70 checkBaseClass (GCDDecl n (Just b) _ _) =
71     do when (n == b) (throwError $ "Class " ++ n ++ " cannot inherit from itself")
72     cs <- gets classes
73     when (isNothing $ lookup b cs) (throwError $ "Class " ++ n ++ " cannot inherit from
        unknown class " ++ b)
74
75 -- | Checks duplicated field declarations
76 checkDuplicateFields :: ClassDeclaration -> ClassAnalyzer ()
77 checkDuplicateFields (GCDDecl n _ fs _) = mapM_ checkField fs
78     where count v = length . filter (\(GDecl _ v') -> v' == v) $ fs
79     checkField (GDecl _ v) = when (count v > 1) (throwError $ "Multiple declarations of
        field " ++ v ++ " in class " ++ n)
80
81 -- | Checks duplicated method declaration in classes
82 checkDuplicateMethods :: ClassDeclaration -> ClassAnalyzer ()
83 checkDuplicateMethods (GCDDecl n _ _ ms) = mapM_ checkMethod ms'
84     where ms' = map (\(GMDDecl n' _ _) -> n') ms
85     count m = length . filter (== m) $ ms'
86     checkMethod m = when (count m > 1) (throwError $ "Multiple definitions of method "
        ++ m ++ " in class " ++ n)
87
88 -- | Checks cyclic inheritance
89 checkCyclicInheritance :: ClassDeclaration -> ClassAnalyzer ()
90 checkCyclicInheritance (GCDDecl _ Nothing _ _) = return ()
91 checkCyclicInheritance (GCDDecl n b _ _) = checkInheritance b [n]
92     where checkInheritance Nothing _ = return ()
93     checkInheritance (Just b') visited =
94         do when (b' `elem` visited) (throwError $ "Cyclic inheritance involving class "
            ++ n)
95         next <- getBaseClass b'
96         checkInheritance next (b' : visited)
97
98 -- | Sets the main class in the Class Analyzer State
99 setMainClass :: ClassDeclaration -> ClassAnalyzer ()
100 setMainClass (GCDDecl n _ _ ms) = when ("main" `elem` ms') (gets mainClass >= set)
101     where
102         ms' = map (\(GMDDecl n' _ _) -> n') ms
103         set (Just m) = throwError $ "Method main already defined in class " ++ m ++ " but
            redefined in class " ++ n
104         set Nothing = modify $ \s -> s {mainClass = Just n}
105
106 -- | Adds classes to the state
107 setClasses :: ClassDeclaration -> ClassAnalyzer ()
108 setClasses c@(GCDDecl n _ _ _) = modify $ \s -> s {classes = (n, c) : classes s}
109
110 -- | Add subclasses to the state
111 setSubClasses :: ClassDeclaration -> ClassAnalyzer ()
112 setSubClasses (GCDDecl n b _ _) = modify (\s -> s { subClasses = (n, []) : subClasses s }) >>
    addSubClass n b
113
114 -- | Adds a subclass to the list of subclasses
115 addSubClass :: TypeName -> Maybe TypeName -> ClassAnalyzer ()
116 addSubClass _ Nothing = return ()
117 addSubClass n (Just b) = gets subClasses >= \sc ->
118     case lookup b sc of
119         Nothing -> modify $ \s -> s { subClasses = (b, [n]) : sc }
120         (Just sc') -> modify $ \s -> s { subClasses = (b, n : sc') : delete (b, sc') sc }
121
122 -- | Sets super classes in the state
123 setSuperClasses :: ClassDeclaration -> ClassAnalyzer ()

```



```

124 setSuperClasses (GCDecl n _ _ _) = gets subClasses >>= \sc ->
125     modify $ \s -> s { superClasses = (n, map fst $ filter (\(_, sub) -> n `elem` sub) sc) :
        superClasses s }
126
127 -- | Returns the nearest 2^n as size for given class
128 getClassSize :: ClassDeclaration -> ClassAnalyzer Size
129 getClassSize (GCDecl _ Nothing fs _) =
130     return $ 2 ^ (ceiling :: Double -> Integer) (logBase 2 (2 + genericLength fs))
131 getClassSize (GCDecl _ (Just b) fs _) =
132     getClass b >>= getClassSize >>= \sz ->
133     return $ 2 ^ (ceiling :: Double -> Integer) (logBase 2 (fromIntegral $ sz +
        genericLength fs))
134
135 -- | Set class size in state
136 setClassSize :: ClassDeclaration -> ClassAnalyzer ()
137 setClassSize c@(GCDecl n _ _ _) =
138     getClassSize c >>= \sz -> modify $ \s -> s { classSize = (n, sz) : classSize s }
139
140 -- | Returns class methods of a passed class
141 resolveClassMethods :: ClassDeclaration -> ClassAnalyzer [MethodDeclaration]
142 resolveClassMethods (GCDecl _ Nothing _ ms) = return ms
143 resolveClassMethods (GCDecl n (Just b) _ ms) = getClass b >>= resolveClassMethods >>= combine
144     where checkSignature (GMDecl m ps _, GMDecl m' ps' _) = when (m == m' && ps /= ps') (
        throwError $ "Method " ++ m ++ " in class " ++ n ++ " has invalid method signature")
145     compareName (GMDecl m _ _) (GMDecl m' _ _) = m == m'
146     combine ms' = mapM_ checkSignature ((,) <$> ms <*> ms') >> return (unionBy
        compareName ms ms')
147
148 -- | Adds the methods of a class in the Class Analyzer State
149 setClassMethods :: ClassDeclaration -> ClassAnalyzer ()
150 setClassMethods c@(GCDecl n _ _ _) = resolveClassMethods c >>= \cm ->
151     modify $ \s -> s { classMethods = (n, cm) : classMethods s }
152
153 -- | Class Analyzes a program
154 caProgram :: Program -> ClassAnalyzer Program
155 caProgram (GProg p) = do
156     mapM_ setClasses p
157     mapM_ setSubClasses p
158     mapM_ setSuperClasses p
159     mapM_ setClassSize p
160     mapM_ setClassMethods p
161     mapM_ checkDuplicateClasses p
162     mapM_ checkDuplicateFields p
163     mapM_ checkDuplicateMethods p
164     mapM_ checkBaseClass p
165     mapM_ checkCyclicInheritance p
166     mapM_ setMainClass p
167     mc <- gets mainClass
168     when (isNothing mc) (throwError "No main method defined")
169     return $ GProg rootClasses
170     where
171         rootClasses = filter noBase p
172         noBase (GCDecl _ Nothing _ _) = True
173         noBase _ = False
174
175 -- | Performs Class Analysis on the program
176 classAnalysis :: Program -> Except String (Program, CState)
177 classAnalysis p = runStateT (runCA $ caProgram p) initialState
178
179 -- | Pretty prints the Class Analyzer State
180 printCState :: (Program, CState) -> IO ()
181 printCState (_, s) = pPrint s

```

ScopeAnalyzer.hs

```
1 {-# LANGUAGE GeneralizedNewtypeDeriving, FlexibleContexts #-}
2
3 module ScopeAnalyzer
4   ( scopeAnalysis
5   , printSASState
6   , SASState(..)
7   ) where
8
9 import Data.Maybe
10 import Data.List
11 import Data.Typeable
12
13 import Control.Monad.State
14 import Control.Monad.Except
15
16 import Debug.Trace (trace, traceShow)
17
18 import Text.Pretty.Simple (pPrint)
19
20 import AST
21 import ClassAnalyzer
22
23 data SASState =
24   SASState {
25     symbolIndex :: SIdentifier,
26     symbolTable  :: SymbolTable,
27     scopeStack  :: [Scope],
28     virtualTables :: [(TypeName, [SIdentifier])],
29     caState     :: CState,
30     mainMethod  :: SIdentifier
31   } deriving (Show, Eq)
32
33 newtype ScopeAnalyzer a = ScopeAnalyzer { runSA :: StateT SASState (Except String) a }
34   deriving (Functor, Applicative, Monad, MonadState SASState, MonadError String)
35
36 initialState :: CState -> SASState
37 initialState s = SASState { symbolIndex = 0, symbolTable = [], scopeStack = [], virtualTables =
38   [], caState = s, mainMethod = 0 }
39
40 -- | Add an empty scope to the scope stack
41 enterScope :: ScopeAnalyzer ()
42 enterScope = modify $ \s -> s { scopeStack = [] : scopeStack s }
43
44 -- | Leaves the current scope by removing it from the scope stack
45 leaveScope :: ScopeAnalyzer ()
46 leaveScope = modify $ \s -> s { scopeStack = drop 1 $ scopeStack s }
47
48 -- | Returns the top scope at the scope stack
49 topScope :: ScopeAnalyzer Scope
50 topScope = gets scopeStack >>= \ss ->
51   case ss of
52     (s:_) -> return s
53     [] -> throwError "ICE: Empty scope stack"
54
55 -- | Add a symbol to the current scope
56 addToScope :: (Identifier, SIdentifier) -> ScopeAnalyzer ()
57 addToScope b =
58   do ts <- topScope
59   modify $ \s -> s { scopeStack = (b : ts) : drop 1 (scopeStack s) }
60
61 -- | Inserts an identifier and symbol pair into the symbol table and current scope
62 saInsert :: Symbol -> Identifier -> ScopeAnalyzer SIdentifier
63 saInsert sym n =
```

```

63     do ts <- topScope
64     when (isJust $ lookup n ts) (throwError $ "Redeclaration of symbol: " ++ n)
65     i <- gets symbolIndex
66     modify $ \s -> s { symbolTable = (i, sym) : symbolTable s, symbolIndex = 1 + i }
67     addToScope (n, i)
68     return i
69
70 -- | Looks up an identifier in the scope
71 saLookup :: Identifier -> ScopeAnalyzer SIdentifier
72 saLookup n = gets scopeStack >= \ss ->
73     case listToMaybe $ mapMaybe (lookup n) ss of
74     Nothing -> throwError $ "Undeclared symbol: " ++ n
75     Just i -> return i
76
77 -- | Scope Analyses Expressions
78 saExpression :: Expression -> ScopeAnalyzer SExpression
79 saExpression (Constant v) = pure $ Constant v
80 saExpression (Variable n) = Variable <$> saLookup n
81 saExpression Nil = pure Nil
82 saExpression (ArrayElement (n, e)) =
83     do n' <- saLookup n
84     e' <- saExpression e
85     return $ ArrayElement (n', e')
86 saExpression (Binary binop e1 e2) =
87     Binary binop
88     <$> saExpression e1
89     <*> saExpression e2
90
91 -- | Scope Analyses Statements
92 saStatement :: Statement -> ScopeAnalyzer SStatement
93 saStatement s =
94     case s of
95     (Assign n modop e) ->
96         when (elem n $ var e) (throwError "Irreversible variable assignment")
97         >> Assign
98         <$> saLookup n
99         <*> pure modop
100        <*> saExpression e
101
102     (AssignArrElem (n, e1) modop e2) ->
103         when (elem (n, e1) $ varArr e2) (throwError "Irreversible variable assignment")
104         >> AssignArrElem
105         <$> saArrayCell n e1
106         <*> pure modop
107         <*> saExpression e2
108
109     (Swap (n1, e1) (n2, e2)) ->
110         Swap
111         <$> maybeArrayCell n1 e1
112         <*> maybeArrayCell n2 e2
113
114     (Conditional e1 s1 s2 e2) ->
115         Conditional
116         <$> saExpression e1
117         <*> mapM saStatement s1
118         <*> mapM saStatement s2
119         <*> saExpression e2
120
121     (Loop e1 s1 s2 e2) ->
122         Loop
123         <$> saExpression e1
124         <*> mapM saStatement s1
125         <*> mapM saStatement s2
126         <*> saExpression e2
127
128     (LocalBlock t n e1 stmt e2) ->

```

```

129     do e1' <- saExpression e1
130     enterScope
131     n' <- saInsert (LocalVariable t n) n
132     stmt' <- mapM saStatement stmt
133     leaveScope
134     e2' <- saExpression e2
135     return $ LocalBlock t n' e1' stmt' e2'
136
137 (LocalCall m args) ->
138   LocalCall
139   <$> saLookup m
140   <*> localCall m args
141
142 (LocalUncall m args) ->
143   LocalUncall
144   <$> saLookup m
145   <*> localCall m args
146
147 (ObjectCall (o, e) m args) ->
148   do when (args /= nub args || (o, e) `elem` args) (throwError $ "Irreversible
149     invocation of method " ++ m)
150   >> ObjectCall
151   <$> maybeArrayCell o e
152   <*> pure m
153   <*> saArgs args
154
155 (ObjectUncall (o, e) m args) ->
156   when (args /= nub args || (o, e) `elem` args) (throwError $ "Irreversible
157     invocation of method " ++ m)
158   >> ObjectUncall
159   <$> maybeArrayCell o e
160   <*> pure m
161   <*> saArgs args
162
163 (ObjectConstruction tp (n, e)) ->
164   ObjectConstruction
165   <$> pure tp
166   <*> maybeArrayCell n e
167
168 (ObjectDestruction tp (n, e)) ->
169   ObjectDestruction
170   <$> pure tp
171   <*> maybeArrayCell n e
172
173 (ObjectBlock tp n stmt) ->
174   do enterScope
175     n' <- saInsert (LocalVariable (ObjectType tp) n) n
176     stmt' <- mapM saStatement stmt
177     leaveScope
178     return $ ObjectBlock tp n' stmt'
179
180 Skip -> pure Skip
181
182 (CopyReference tp (n, e1) (m, e2)) ->
183   CopyReference
184   <$> pure tp
185   <*> maybeArrayCell n e1
186   <*> maybeArrayCell m e2
187
188 (UnCopyReference tp (n, e1) (m, e2)) ->
189   UnCopyReference
190   <$> pure tp
191   <*> maybeArrayCell n e1
192   <*> maybeArrayCell m e2
193
194 (ArrayConstruction (tp, e) n) ->

```

```

193         do n' <- saLookup n
194         e' <- saExpression e
195         return $ ArrayConstruction (tp, e') n'
196
197     (ArrayDestruction (tp, e) n) ->
198         do n' <- saLookup n
199         e' <- saExpression e
200         return $ ArrayDestruction (tp, e') n'
201
202     where var (Variable n) = [n]
203           var (Binary _ e1 e2) = var e1 ++ var e2
204           var _ = []
205
206           varArr (ArrayElement (n, e)) = [(n, e)]
207           varArr _ = []
208
209           isCF ClassField{} = True
210           isCF _ = False
211
212           rlookup = flip lookup
213
214           localCall :: MethodName -> [(Identifier, Maybe Expression)] -> ScopeAnalyzer [(
215               SIdentifier, Maybe SExpression)]
216           localCall m args =
217             do when (args /= nub args) (throwError $ "Irreversible invocation of method " ++ m
218               )
219             args' <- saArgs args
220             st <- gets symbolTable
221             when (any isCF $ mapMaybe (rlookup st . fst) args') (throwError $ "Irreversible
222               invocation of method " ++ m)
223             return args'
224
225           saArgs :: [(Identifier, Maybe Expression)] -> ScopeAnalyzer [(SIdentifier, Maybe
226               SExpression)]
227           saArgs args =
228             do (ns, es) <- pure $ unzip args
229             ns' <- mapM saLookup ns
230             es' <- mapM (mapM saExpression) es
231             return $ zip ns' es'
232
233           maybeArrayCell :: Identifier -> Maybe Expression -> ScopeAnalyzer (SIdentifier,
234               Maybe SExpression)
235           maybeArrayCell n e =
236             do n' <- saLookup n
237             e' <- mapM saExpression e
238             return (n', e')
239
240           saArrayCell :: Identifier -> Expression -> ScopeAnalyzer (SIdentifier, SExpression)
241           saArrayCell n e =
242             do n' <- saLookup n
243             e' <- saExpression e
244             return (n', e')
245
246 -- | Set the main method in the Scope Analyzer state
247 setMainMethod :: SIdentifier -> ScopeAnalyzer ()
248 setMainMethod i = modify $ \s -> s { mainMethod = i }
249
250 -- | Scope Analyses Methods
251 saMethod :: (TypeName, MethodDeclaration) -> ScopeAnalyzer (TypeName, SMethodDeclaration)
252 saMethod (t, GMDecl m ps body) =
253     do m' <- saLookup m
254     when (m == "main") (setMainMethod m')
255     enterScope
256     ps' <- mapM insertMethodParameter ps
257     body' <- mapM saStatement body
258     leaveScope

```

```

254     return (t, GMDecl m' ps' body')
255     where insertMethodParameter (GDecl tp n) = GDecl tp <$> saInsert (MethodParameter tp n) n
256
257 -- | Returns subclasses for a given type name
258 getSubClasses :: TypeName -> ScopeAnalyzer [ClassDeclaration]
259 getSubClasses n =
260     do cs <- gets $ classes . caState
261        sc <- gets $ subClasses . caState
262        case lookup n sc of
263            Nothing -> throwError $ "ICE: Unknown class " ++ n
264            (Just sc') -> return $ mapMaybe (rlookup cs) sc'
265     where rlookup = flip lookup
266
267 -- | Returns method name at given index
268 getMethodName :: SIdentifier -> ScopeAnalyzer (SIdentifier, MethodName)
269 getMethodName i = gets symbolTable >=> \st ->
270     case lookup i st of
271         (Just (Method _ m)) -> return (i, m)
272         _ -> throwError $ "ICE: Invalid method index " ++ show i
273
274 -- | Prefixes the virtual table
275 prefixVtable :: [(SIdentifier, MethodName)] -> (SIdentifier, MethodName) -> [(SIdentifier,
276     MethodName)]
277 prefixVtable [] m' = [m']
278 prefixVtable (m:ms) m' = if comp m m' then m':ms else m : prefixVtable ms m'
279     where comp (_, n) (_, n') = n == n'
280
281 -- | Scope Analyses a passed class
282 saClass :: Offset -> [SIdentifier] -> ClassDeclaration -> ScopeAnalyzer [(TypeName,
283     SMethodDeclaration)]
284 saClass offset pids (GDecl c _ fs ms) =
285     do enterScope
286        mapM_ insertClassField $ zip [offset..] fs
287        m1 <- mapM getMethodName pids
288        m2 <- mapM insertMethod ms
289        let m3 = map fst $ foldl prefixVtable m1 m2
290            offset' = genericLength fs + offset
291            modify $ \s -> s { virtualTables = (c, m3) : virtualTables s }
292            sc <- getSubClasses c
293            ms' <- concat <$> mapM (saClass offset' m3) sc
294            ms'' <- mapM saMethod $ zip (repeat c) ms
295            leaveScope
296            return $ ms' ++ ms''
297     where insertClassField (o, GDecl tp n) = saInsert (ClassField tp n c o) n
298           insertMethod (GMDecl n ps _) = saInsert (Method (map getType ps) n) n >=>
299               getMethodName
300           getType (GDecl tp _) = tp
301
302 -- | Analyses Programs
303 saProgram :: Program -> ScopeAnalyzer SProgram
304 saProgram (GProg cs) = concat <$> mapM (saClass 2 []) cs
305
306 -- | Performs scope analysis on the entire program
307 scopeAnalysis :: (Program, CState) -> Except String (SProgram, SState)
308 scopeAnalysis (p, s) = runStateT (runSA $ saProgram p) $ initialState s
309
310 -- | Pretty prints the current Scope Analysis State Monad
311 printSState :: (Show a, MonadIO m) => (t, a) -> m ()
312 printSState (_, s) = pPrint s

```

TypeChecker.hs

```
1 {-# LANGUAGE GeneralizedNewtypeDeriving #-}
2
3 module TypeChecker (typeCheck) where
4
5 import Data.List
6 import Data.Maybe
7
8 import Control.Monad.Reader
9 import Control.Monad.Except
10 import Control.Exception
11
12 import Debug.Trace (trace, traceShow)
13
14 import AST
15 import ClassAnalyzer
16 import ScopeAnalyzer
17
18 newtype TypeChecker a = TypeChecker { runTC :: ReaderT SASTate (Except String) a }
19   deriving (Functor, Applicative, Monad, MonadReader SASTate, MonadError String)
20
21 getType :: SIdentifier -> TypeChecker DataType
22 getType i = asks symbolTable >=> \st ->
23   case lookup i st of
24     (Just (LocalVariable t _)) -> return t
25     (Just (ClassField t _ _)) -> return t
26     (Just (MethodParameter t _)) -> return t
27     _ -> throwError $ "ICE: Invalid index " ++ show i
28
29 getParameterTypes :: SIdentifier -> TypeChecker [DataType]
30 getParameterTypes i = asks symbolTable >=> \st ->
31   case lookup i st of
32     (Just (Method ps _)) -> return ps
33     _ -> throwError $ "ICE: Invalid index " ++ show i
34
35 expectType :: DataType -> DataType -> TypeChecker ()
36 expectType t1 t2 = unless (t1 == t2) (throwError $ "Expected type: " ++ show t1 ++ "\nActual
   type: " ++ show t2)
37
38 getClassMethods :: TypeName -> TypeChecker [MethodDeclaration]
39 getClassMethods n = asks (classMethods . caState) >=> \cm ->
40   case lookup n cm of
41     Nothing -> throwError $ "ICE: Unknown class " ++ n
42     (Just ms) -> return ms
43
44 getDynamicParameterTypes :: TypeName -> MethodName -> TypeChecker [DataType]
45 getDynamicParameterTypes n m = getClassMethods n >=> \ms ->
46   case find (\(GMDecl m' _ _) -> m == m') ms of
47     Nothing -> throwError $ "Class " ++ n ++ " does not support method " ++ m
48     (Just (GMDecl _ ps _)) -> return $ map (\(GDecl tp _) -> tp) ps
49
50 getArrayType :: DataType -> DataType
51 getArrayType tp = case tp of
52   IntegerArrayType -> IntegerType
53   ObjectArrayType t -> ObjectType t
54
55 checkCall :: [(SIdentifier, Maybe SExpression)] -> [DataType] -> TypeChecker ()
56 checkCall args ps =
57   when (la /= lp) (throwError err)
58   >> mapM (mapM tcExpression . snd) args
59   >> mapM (getType . fst) args
60   >> \as -> mapM_ checkArgument (zip as ps)
61   where la = length args
62         lp = length ps
```

```

63         err = "Passed " ++ show la ++ " argument(s) to method expecting " ++ show lp ++ "
           argument(s) "
64
65 checkArgument :: (DataType, DataType) -> TypeChecker ()
66 checkArgument (ObjectType ca, ObjectType cp) = asks (superClasses . caState) >>= \sc ->
67     unless (ca == cp || maybe False (elem cp) (lookup ca sc)) (throwError $ "Class " ++ ca ++
           " not a subtype of class " ++ cp)
68 checkArgument (ObjectType ca, ObjectArrayType cp) = asks (superClasses . caState) >>= \sc ->
69     unless (ca == cp || maybe False (elem cp) (lookup ca sc)) (throwError $ "Class " ++ ca ++
           " not a subtype of class " ++ cp)
70 checkArgument (ObjectArrayType ca, ObjectType cp) = asks (superClasses . caState) >>= \sc ->
71     unless (ca == cp || maybe False (elem cp) (lookup ca sc)) (throwError $ "Class " ++ ca ++
           " not a subtype of class " ++ cp)
72 checkArgument (IntegerArrayType, tp) = expectType (getArrayType IntegerArrayType) tp
73 checkArgument (ta, IntegerArrayType) = expectType (getArrayType IntegerArrayType) ta
74 checkArgument (ta, tp) = expectType tp ta
75
76 tcExpression :: SExpression -> TypeChecker DataType
77 tcExpression (Constant _) = pure IntegerType
78 tcExpression (Variable n) = getType n
79 tcExpression Nil = pure NilType
80 tcExpression (ArrayElement (n, e)) =
81     do t <- getType n
82     expectType ArrayType t
83     e' <- tcExpression e
84     expectType IntegerType e'
85     return $ getArrayType t
86 tcExpression (Binary binop e1 e2)
87     | binop == Eq || binop == Neq =
88     do t1 <- tcExpression e1
89     t2 <- tcExpression e2
90     expectType t1 t2
91     pure IntegerType
92     | otherwise =
93     do t1 <- tcExpression e1
94     t2 <- tcExpression e2
95     expectType t1 IntegerType
96     expectType t2 IntegerType
97     pure IntegerType
98
99 tcStatement :: SStatement -> TypeChecker ()
100 tcStatement s =
101     case s of
102     (Assign n _ e) ->
103         getType n
104         >>= expectType IntegerType
105         >> tcExpression e
106         >>= expectType IntegerType
107
108     (AssignArrElem (n, e1) _ e2) ->
109         getType n
110         >>= expectType IntegerArrayType
111         >> tcExpression e1
112         >>= expectType IntegerType
113         >> tcExpression e2
114         >>= expectType IntegerType
115
116     (Swap (n1, e1) (n2, e2)) ->
117         do t1 <- getType n1
118         t2 <- getType n2
119         if isNothing e1 /= isNothing e2
120         then catchError (checkArgument (t1, t2)) (\_ -> checkArgument (t2, t1))
121         else expectType (if isNothing e1 then t1 else getArrayType t1) (if isNothing
           e2 then t2 else getArrayType t2)
122
123     (Conditional e1 s1 s2 e2) ->

```



```

124         tcExpression e1
125         >>= expectType IntegerType
126         >> mapM_ tcStatement s1
127         >> mapM_ tcStatement s2
128         >> tcExpression e2
129         >>= expectType IntegerType
130
131     (Loop e1 s1 s2 e2) ->
132         tcExpression e1
133         >>= expectType IntegerType
134         >> mapM_ tcStatement s1
135         >> mapM_ tcStatement s2
136         >> tcExpression e2
137         >>= expectType IntegerType
138
139     (ObjectBlock _ _ stmt) ->
140         mapM_ tcStatement stmt
141
142     (LocalBlock t n e1 stmt e2) ->
143         getType n
144         >> tcExpression e1
145         >>= expectType (if t == IntegerType then IntegerType else NilType)
146         >> mapM_ tcStatement stmt
147         >> tcExpression e2
148         >>= expectType (if t == IntegerType then IntegerType else NilType)
149
150     (LocalCall m args) ->
151         getParameterTypes m
152         >>= checkCall args
153
154     (LocalUncall m args) ->
155         getParameterTypes m
156         >>= checkCall args
157
158     (ObjectCall (o, e) m args) ->
159         do t <- getType o
160         e' <- mapM tcExpression e
161         case t of
162             (ObjectType tn) -> getDynamicParameterTypes tn m >>= checkCall args
163             (ObjectArrayType tn) ->
164                 case e' of
165                     Nothing -> throwError $ "Non-object type " ++ show t ++ " does not
166                                     support method invocation"
167                     _ -> getDynamicParameterTypes tn m >>= checkCall args
168                     _ -> throwError $ "Non-object type " ++ show t ++ " does not support method
169                                     invocation"
170
171     (ObjectUncall (o, e) m args) ->
172         do t <- getType o
173         e' <- mapM tcExpression e
174         case t of
175             (ObjectType tn) -> getDynamicParameterTypes tn m >>= checkCall args
176             (ObjectArrayType tn) ->
177                 case e' of
178                     Nothing -> throwError $ "Non-object type " ++ show t ++ " does not
179                                     support method invocation"
180                     _ -> getDynamicParameterTypes tn m >>= checkCall args
181                     _ -> throwError $ "Non-object type " ++ show t ++ " does not support method
182                                     invocation"
183
184     Skip -> pure ()
185
186     (ObjectConstruction tp (n, e)) ->
187         do t <- getType n
188         e' <- mapM tcExpression e
189         case e' of

```

```

186         Nothing -> expectType t (ObjectType tp)
187         _        -> checkArgument (ObjectType tp, t)
188
189     (ObjectDestruction tp (n, e)) ->
190         do t <- getType n
191         _ <- mapM tcExpression e
192         case t of
193             (ObjectType _) -> expectType t (ObjectType tp)
194             (ObjectArrayType _) -> checkArgument (ObjectType tp, t)
195             _ -> throwError $ "Expected type: " ++ show (ObjectType tp) ++ " Actual type: " ++ show t
196
197     -- Allow copying with a copy type
198     CopyReference _ (n, e1) (m, e2) ->
199         do t1 <- getType n
200         t2 <- getType m
201         e1' <- mapM tcExpression e1
202         e2' <- mapM tcExpression e2
203         when (t1 == IntegerType || t2 == IntegerType) (throwError "Integer types does not support reference copying")
204         if isNothing e1 /= isNothing e2
205             then catchError (checkArgument (t1, t2)) (\_ -> checkArgument (t2, t1))
206             else expectType (if isNothing e1 then t1 else getArrayType t1) (if isNothing e2 then t2 else getArrayType t2)
207
208     -- Allow uncopying with two identical copies
209     UnCopyReference _ (n, e1) (m, e2) ->
210         do t1 <- getType n
211         t2 <- getType m
212         e1' <- mapM tcExpression e1
213         e2' <- mapM tcExpression e2
214         when (t1 == IntegerType || t2 == IntegerType) (throwError "Integer types does not support reference copying")
215         if isNothing e1 /= isNothing e2
216             then catchError (checkArgument (t1, t2)) (\_ -> checkArgument (t2, t1))
217             else expectType (if isNothing e1 then t1 else getArrayType t1) (if isNothing e2 then t2 else getArrayType t2)
218
219
220     (ArrayConstruction (tp, e) n) ->
221         do t <- getType n
222         _ <- tcExpression e
223         case tp of
224             "int" -> expectType t IntegerArrayType
225             _     -> expectType t (ObjectArrayType tp)
226
227     (ArrayDestruction (tp, e) n) ->
228         do t <- getType n
229         _ <- tcExpression e
230         case tp of
231             "int" -> expectType t IntegerArrayType
232             _     -> checkArgument (ObjectArrayType tp, t)
233
234     getMethodName :: SIdentifier -> TypeChecker Identifier
235     getMethodName i = asks symbolTable >>= \st ->
236         case lookup i st of
237             (Just (Method _ n)) -> return n
238             _ -> throwError $ "ICE: Invalid index " ++ show i
239
240     tcMethod :: (TypeName, SMethodDeclaration) -> TypeChecker ()
241     tcMethod (_, GMDecl _ [] body) = mapM_ tcStatement body
242     tcMethod (_, GMDecl i ([:_]) body) = getMethodName i >>= \n ->
243         when (n == "main") (throwError "Method main has invalid signature")
244         >> mapM_ tcStatement body
245
246     tcProgram :: SProgram -> TypeChecker (SProgram, SASTate)

```

```
247 tcProgram p = (,) p <$> (mapM_ tcMethod p >> ask)
248
249 typeCheck :: (SProgram, SASTate) -> Except String (SProgram, SASTate)
250 typeCheck (p, s) = runReaderT (runTC $ tcProgram p) s
```

CodeGenerator.hs

```
1 {-# LANGUAGE GeneralizedNewtypeDeriving #-}
2 {-# LANGUAGE ScopedTypeVariables      #-}
3
4 module CodeGenerator(
5     generatePISA,
6     showPISAProgram
7 ) where
8
9 import Data.List
10
11 import Control.Arrow
12 import Control.Monad.Except
13 import Control.Monad.State
14
15 import Debug.Trace (trace, traceShow)
16
17 import Text.Pretty.Simple (pPrint)
18
19 import AST
20 import ClassAnalyzer
21 import PISA
22 import ScopeAnalyzer
23
24 {-# ANN module "HLint: ignore Reduce duplication" #-}
25
26 data CGState =
27     CGState {
28         labelIndex :: SIdentifier,
29         registerIndex :: Integer,
30         labelTable :: [(SIdentifier, Label)],
31         registerStack :: [(SIdentifier, Register)],
32         saState :: SASState
33     } deriving (Show, Eq)
34
35 newtype CodeGenerator a = CodeGenerator { runCG :: StateT CGState (Except String) a }
36     deriving (Functor, Applicative, Monad, MonadState CGState, MonadError String)
37
38
39 initialState :: SASState -> CGState
40 initialState s = CGState { labelIndex = 0, registerIndex = 6, labelTable = [], registerStack =
41     [], saState = s }
42
43 -- | Register containing 0
44 registerZero :: Register
45 registerZero = Reg 0
46
47 -- | Register containing Stack pointer
48 registerSP :: Register
49 registerSP = Reg 1
50
51 -- | Register R0
52 registerRO :: Register
53 registerRO = Reg 2
54
55 -- | Register holding 'this'
56 registerThis :: Register
57 registerThis = Reg 3
58
59 -- | Register containing Free list pointers
60 registerFLPs :: Register
61 registerFLPs = Reg 4
62
63 -- | Register containing Heap pointer
```

```

63 registerHP :: Register
64 registerHP = Reg 5
65
66 -- | Pushes a new register to the register stack
67 pushRegister :: SIdentifier -> CodeGenerator Register
68 pushRegister i = do ri <- gets registerIndex
69                     modify $ \s -> s { registerIndex = 1 + ri, registerStack = (i, Reg ri) :
                                           registerStack s }
70                     return $ Reg ri
71
72 -- | Pop a register from the register stack
73 popRegister :: CodeGenerator ()
74 popRegister = modify $ \s -> s { registerIndex = (-1) + registerIndex s, registerStack = drop
                                   1 $ registerStack s }
75
76 -- | Reserve a tmp register
77 tempRegister :: CodeGenerator Register
78 tempRegister =
79     do ri <- gets registerIndex
80     modify $ \s -> s { registerIndex = 1 + ri }
81     return $ Reg ri
82
83 -- | Clear reserved tmp register
84 popTempRegister :: CodeGenerator ()
85 popTempRegister = modify $ \s -> s { registerIndex = (-1) + registerIndex s }
86
87 -- | Lookup register of given identifier
88 lookupRegister :: SIdentifier -> CodeGenerator Register
89 lookupRegister i = gets registerStack >= \rs ->
90     case lookup i rs of
91         Nothing -> throwError $ "ICE: No register reserved for index " ++ show i
92         (Just r) -> return r
93
94 -- | Returns the method name of a valid method identifier
95 getMethodName :: SIdentifier -> CodeGenerator MethodName
96 getMethodName i = gets (symbolTable . saState) >= \st ->
97     case lookup i st of
98         (Just (Method _ n)) -> return n
99         _ -> throwError $ "ICE: Invalid method index " ++ show i
100
101 -- | Inserts a unique method label in the label table for a given method identifier
102 insertMethodLabel :: SIdentifier -> CodeGenerator ()
103 insertMethodLabel m =
104     do n <- getMethodName m
105     i <- gets labelIndex
106     modify $ \s -> s { labelIndex = 1 + i, labelTable = (m, "l_" ++ n ++ "_" ++ show i) :
                       labelTable s }
107
108 -- | Returns the Method label for a method identifier
109 getMethodLabel :: SIdentifier -> CodeGenerator Label
110 getMethodLabel m = gets labelTable >= \lt ->
111     case lookup m lt of
112         (Just l) -> return l
113         Nothing -> insertMethodLabel m >> getMethodLabel m
114
115 -- | Returns a unique label by appending the label index to a passed label type
116 getUniqueLabel :: Label -> CodeGenerator Label
117 getUniqueLabel l =
118     do i <- gets labelIndex
119     modify $ \s -> s { labelIndex = 1 + i }
120     return $ l ++ "_" ++ show i
121
122 -- | Returns the address to the variable of a given identifier
123 loadVariableAddress :: SIdentifier -> CodeGenerator (Register, [(Maybe Label, MInstruction)],
124     CodeGenerator ())
125 loadVariableAddress n = gets (symbolTable . saState) >= \st ->

```

```

125     case lookup n st of
126       (Just (ClassField _ _ o)) -> tempRegister >=> \r -> return (r, [(Nothing, ADD r
          registerThis), (Nothing, ADDI r $ Immediate o)], popTempRegister)
127       (Just (LocalVariable _ _)) -> lookupRegister n >=> \r -> return (r, [], return ())
128       (Just (MethodParameter _ _)) -> lookupRegister n >=> \r -> return (r, [], return ())
129       _ -> throwError $ "ICE: Invalid variable index " ++ show n
130
131 -- | Returns the value of a variable of given identifier
132 loadVariableValue :: SIdentifier -> CodeGenerator (Register, [(Maybe Label, MInstruction)],
          CodeGenerator ())
133 loadVariableValue n =
134   do (ra, la, ua) <- loadVariableAddress n
135   rv <- tempRegister
136   return (rv, la ++ [(Nothing, EXCH rv ra)] ++ invertInstructions la, popTempRegister >>
          ua)
137
138 -- | Returns address an array element
139 loadArrayElementVariableAddress :: SIdentifier -> SExpression -> CodeGenerator (Register, [(
          Maybe Label, MInstruction)], CodeGenerator ())
140 loadArrayElementVariableAddress n e =
141   do (ra, la, ua) <- loadVariableAddress n
142   (re, le, ue) <- cgExpression e
143   rv <- tempRegister
144   rt <- tempRegister
145   return (rv, la ++ le ++ [(Nothing, EXCH rt ra), (Nothing, XOR rv rt), (Nothing, EXCH rt
          ra), (Nothing, ADDI rv ArrayElementOffset), (Nothing, ADD rv re)] ++
          invertInstructions (la ++ le), popTempRegister >> popTempRegister >> ue >> ua)
146
147 -- | Returns the value of an array element
148 loadArrayElementVariableValue :: SIdentifier -> SExpression -> CodeGenerator (Register, [(
          Maybe Label, MInstruction)], CodeGenerator ())
149 loadArrayElementVariableValue n e =
150   do (ra, la, ua) <- loadArrayElementVariableAddress n e
151   rv <- tempRegister
152   return (rv, la ++ [(Nothing, EXCH rv ra)] ++ invertInstructions la, popTempRegister >>
          ua)
153
154 -- | Returns pointer to free list at given index
155 loadFreeListAddress :: Register -> CodeGenerator (Register, [(Maybe Label, MInstruction)],
          CodeGenerator ())
156 loadFreeListAddress index = tempRegister >=> \rt -> return (rt, [(Nothing, XOR rt registerFLPs
          ), (Nothing, ADD rt index)], popTempRegister)
157
158 -- | Returns a copy of the pointer to the head of the free list at the given register
159 loadHeadAtFreeList :: Register -> CodeGenerator (Register, [(Maybe Label, MInstruction)],
          CodeGenerator ())
160 loadHeadAtFreeList rFreeList =
161   do rv <- tempRegister
162   rt <- tempRegister
163   let copyAddress = [(Nothing, EXCH rt rFreeList),
164                     (Nothing, XOR rv rt),
165                     (Nothing, EXCH rt rFreeList)]
166   return (rv, copyAddress, popTempRegister >> popTempRegister)
167
168 -- | Code generation for binary operators
169 cgBinOp :: BinOp -> Register -> Register -> CodeGenerator (Register, [(Maybe Label,
          MInstruction)], CodeGenerator ())
170 cgBinOp Add r1 r2 = tempRegister >=> \rt -> return (rt, [(Nothing, XOR rt r1), (Nothing, ADD
          rt r2)], popTempRegister)
171 cgBinOp Sub r1 r2 = tempRegister >=> \rt -> return (rt, [(Nothing, XOR rt r1), (Nothing, SUB
          rt r2)], popTempRegister)
172 cgBinOp Xor r1 r2 = tempRegister >=> \rt -> return (rt, [(Nothing, XOR rt r1), (Nothing, XOR
          rt r2)], popTempRegister)
173 cgBinOp BitAnd r1 r2 = tempRegister >=> \rt -> return (rt, [(Nothing, ANDX rt r1 r2)],
          popTempRegister)

```

```

174 cgBinOp BitOr r1 r2 = tempRegister >>= \rt -> return (rt, [(Nothing, ORX rt r1 r2)],
    popTempRegister)
175 cgBinOp Lt r1 r2 =
176     do rt <- tempRegister
177         rc <- tempRegister
178         l_top <- getUniqueLabel "cmp_top"
179         l_bot <- getUniqueLabel "cmp_bot"
180         let cmp = [(Nothing, XOR rt r1),
181                     (Nothing, SUB rt r2),
182                     (Just l_top, BGEZ rt l_bot),
183                     (Nothing, XORI rc $ Immediate 1),
184                     (Just l_bot, BGEZ rt l_top)]
185         return (rc, cmp, popTempRegister >> popTempRegister)
186 cgBinOp Gt r1 r2 =
187     do rt <- tempRegister
188         rc <- tempRegister
189         l_top <- getUniqueLabel "cmp_top"
190         l_bot <- getUniqueLabel "cmp_bot"
191         let cmp = [(Nothing, XOR rt r1),
192                     (Nothing, SUB rt r2),
193                     (Just l_top, BLEZ rt l_bot),
194                     (Nothing, XORI rc $ Immediate 1),
195                     (Just l_bot, BLEZ rt l_top)]
196         return (rc, cmp, popTempRegister >> popTempRegister)
197 cgBinOp Eq r1 r2 =
198     do rt <- tempRegister
199         l_top <- getUniqueLabel "cmp_top"
200         l_bot <- getUniqueLabel "cmp_bot"
201         let cmp = [(Just l_top, BNE r1 r2 l_bot),
202                     (Nothing, XORI rt $ Immediate 1),
203                     (Just l_bot, BNE r1 r2 l_top)]
204         return (rt, cmp, popTempRegister)
205 cgBinOp Neq r1 r2 =
206     do rt <- tempRegister
207         l_top <- getUniqueLabel "cmp_top"
208         l_bot <- getUniqueLabel "cmp_bot"
209         let cmp = [(Just l_top, BEQ r1 r2 l_bot),
210                     (Nothing, XORI rt $ Immediate 1),
211                     (Just l_bot, BEQ r1 r2 l_top)]
212         return (rt, cmp, popTempRegister)
213 cgBinOp Lte r1 r2 =
214     do rt <- tempRegister
215         rc <- tempRegister
216         l_top <- getUniqueLabel "cmp_top"
217         l_bot <- getUniqueLabel "cmp_bot"
218         let cmp = [(Nothing, XOR rt r1),
219                     (Nothing, SUB rt r2),
220                     (Just l_top, BGTZ rt l_bot),
221                     (Nothing, XORI rc $ Immediate 1),
222                     (Just l_bot, BGTZ rt l_top)]
223         return (rc, cmp, popTempRegister >> popTempRegister)
224 cgBinOp Gte r1 r2 =
225     do rt <- tempRegister
226         rc <- tempRegister
227         l_top <- getUniqueLabel "cmp_top"
228         l_bot <- getUniqueLabel "cmp_bot"
229         let cmp = [(Nothing, XOR rt r1),
230                     (Nothing, SUB rt r2),
231                     (Just l_top, BLTZ rt l_bot),
232                     (Nothing, XORI rc $ Immediate 1),
233                     (Just l_bot, BLTZ rt l_top)]
234         return (rc, cmp, popTempRegister >> popTempRegister)
235 cgBinOp _ _ _ = throwError "ICE: Binary operator not implemented"
236
237 -- | Code generation for expressions

```

```

238 cgExpression :: SExpression -> CodeGenerator (Register, [(Maybe Label, MInstruction)],
      CodeGenerator ())
239 cgExpression (Constant 0) = return (registerZero, [], return ())
240 cgExpression (Constant n) = tempRegister >>= \rt -> return (rt, [(Nothing, XORI rt $ Immediate
      n)], popTempRegister)
241 cgExpression (Variable i) = loadVariableValue i
242 cgExpression (ArrayElement (n, e)) = loadArrayElementVariableValue n e
243 cgExpression Nil = return (registerZero, [], return ())
244 cgExpression (Binary op e1 e2) =
245     do (r1, l1, u1) <- cgExpression e1
246        (r2, l2, u2) <- cgExpression e2
247        (ro, lo, uo) <- cgBinOp op r1 r2
248        return (ro, l1 ++ l2 ++ lo, uo >> u2 >> u1)
249
250 -- | Code generation for binary expressions
251 cgBinaryExpression :: SExpression -> CodeGenerator (Register, [(Maybe Label, MInstruction)],
      CodeGenerator ())
252 cgBinaryExpression e =
253     do (re, le, ue) <- cgExpression e
254        rt <- tempRegister
255        l_top <- getUniqueLabel "f_top"
256        l_bot <- getUniqueLabel "f_bot"
257        let flatten = [(Just l_top, BEQ re registerZero l_bot),
258                      (Nothing, XORI rt $ Immediate 1),
259                      (Just l_bot, BEQ re registerZero l_top)]
260        return (rt, le ++ flatten, popTempRegister >> ue)
261
262 -- | Code generation for assignments
263 cgAssign :: SIdentifier -> ModOp -> SExpression -> CodeGenerator [(Maybe Label, MInstruction)]
264 cgAssign n modop e =
265     do (rt, lt, ut) <- loadVariableValue n
266        (re, le, ue) <- cgExpression e
267        ue >> ut
268        return $ lt ++ le ++ [(Nothing, cgModOp modop rt re)] ++ invertInstructions (lt ++ le)
269     where cgModOp ModAdd = ADD
270           cgModOp ModSub = SUB
271           cgModOp ModXor = XOR
272
273 -- | Code generation for assignments
274 cgAssignArrElem :: (SIdentifier, SExpression) -> ModOp -> SExpression -> CodeGenerator [(Maybe
      Label, MInstruction)]
275 cgAssignArrElem (n, e1) modop e2 =
276     do (rt, lt, ut) <- loadArrayElementVariableValue n e1
277        (re, le, ue) <- cgExpression e2
278        l <- getUniqueLabel "assArrElem"
279        ue >> ut
280        return $ lt ++ le ++ [(Just l, cgModOp modop rt re)] ++ invertInstructions (lt ++ le)
281     where cgModOp ModAdd = ADD
282           cgModOp ModSub = SUB
283           cgModOp ModXor = XOR
284
285 -- | Ensures correct loads for swapping
286 loadForSwap :: (SIdentifier, Maybe SExpression) -> CodeGenerator (Register, [(Maybe Label,
      MInstruction)], CodeGenerator ())
287 loadForSwap (n, x) = gets (symbolTable . saState) >>= \st ->
288     case lookup n st of
289         (Just (ClassField IntegerArrayType _ _)) -> case x of
290             Just x' ->
291                 loadArrayElementVariableValue n x'
292                 _ -> loadVariableValue n
293         (Just (ClassField (ObjectArrayType _) _ _)) -> case x of
294             Just x' ->
295                 loadArrayElementVariableValue n x'
296                 _ -> loadVariableValue n
297         (Just ClassField {}) -> loadVariableValue n
298         (Just (LocalVariable IntegerType _)) -> loadVariableValue n

```



```

297     (Just (LocalVariable (ObjectType _) _)) -> loadVariableValue n
298     (Just (LocalVariable (CopyType _) _)) -> loadVariableValue n
299     (Just (LocalVariable IntegerArrayType _) -> case x of
300         Just x' ->
301             loadArrayElementVariableValue n x'
302             _ -> loadVariableValue n
303     (Just (LocalVariable (ObjectArrayType _) _)) -> case x of
304         Just x' ->
305             loadArrayElementVariableValue n x'
306             _ -> loadVariableValue n
307     (Just (MethodParameter IntegerType _) -> loadVariableValue n
308     (Just (MethodParameter (ObjectType _) _) -> loadVariableValue n
309     (Just (MethodParameter (CopyType _) _) -> loadVariableValue n
310     (Just (MethodParameter IntegerArrayType _) -> case x of
311         Just x' ->
312             loadArrayElementVariableValue n x'
313             _ -> loadVariableValue n
314     (Just (MethodParameter (ObjectArrayType _) _) -> case x of
315         Just x' ->
316             loadArrayElementVariableValue n x'
317             _ -> loadVariableValue n
318     _ -> throwError $ "ICE: Invalid variable index " ++ show n
319
320 -- | Code generation for swaps
321 cgSwap :: (SIdentifier, Maybe SExpression) -> (SIdentifier, Maybe SExpression) ->
322     CodeGenerator [(Maybe Label, MInstruction)]
323 cgSwap n1 n2 = if n1 == n2 then return [] else
324     do (r1, l1, u1) <- loadForSwap n1
325     (r2, l2, u2) <- loadForSwap n2
326     u2 >> u1
327     l <- getUniqueLabel "swap"
328     let swap = [(Just l, XOR r1 r2), (Nothing, XOR r2 r1), (Nothing, XOR r1 r2)]
329     return $ l1 ++ l2 ++ swap ++ invertInstructions (l1 ++ l2)
330
331 -- | Code generation for conditionals
332 cgConditional :: SExpression -> [SStatement] -> [SStatement] -> SExpression -> CodeGenerator
333     [(Maybe Label, MInstruction)]
334 cgConditional e1 s1 s2 e2 =
335     do l_test <- getUniqueLabel "test"
336     l_assert_t <- getUniqueLabel "assert_true"
337     l_test_f <- getUniqueLabel "test_false"
338     l_assert <- getUniqueLabel "assert"
339     rt <- tempRegister
340     (rel, lel, ue1) <- cgBinaryExpression e1
341     ue1
342     s1' <- concat <$> mapM cgStatement s1
343     s2' <- concat <$> mapM cgStatement s2
344     (re2, le2, ue2) <- cgBinaryExpression e2
345     ue2 >> popTempRegister --rt
346     return $ lel ++ [(Nothing, XOR rt rel)] ++ invertInstructions lel ++
347         [(Just l_test, BEQ rt registerZero l_test_f), (Nothing, XORI rt $ Immediate 1)
348         ] ++
349         s1' ++ [(Nothing, XORI rt $ Immediate 1), (Just l_assert_t, BRA l_assert), (
350             Just l_test_f, BRA l_test)] ++
351         s2' ++ [(Just l_assert, BNE rt registerZero l_assert_t)] ++
352         le2 ++ [(Nothing, XOR rt re2)] ++ invertInstructions le2
353
354 -- | Code generation for loops
355 cgLoop :: SExpression -> [SStatement] -> [SStatement] -> SExpression -> CodeGenerator [(Maybe
356     Label, MInstruction)]
357 cgLoop e1 s1 s2 e2 =
358     do l_entry <- getUniqueLabel "entry"
359     l_test <- getUniqueLabel "test"
360     l_assert <- getUniqueLabel "assert"

```

```

352     l_exit <- getUniqueLabel "exit"
353     rt <- tempRegister
354     (re1, le1, ue1) <- cgBinaryExpression e1
355     ue1
356     s1' <- concat <$> mapM cgStatement s1
357     s2' <- concat <$> mapM cgStatement s2
358     (re2, le2, ue2) <- cgBinaryExpression e2
359     ue2 >> popTempRegister --rt
360     return $ [(Nothing, XORI rt $ Immediate 1), (Just l_entry, BEQ rt registerZero l_assert
        )] ++
361         le1 ++ [(Nothing, XOR rt re1)] ++ invertInstructions le1 ++
362         s1' ++ le2 ++ [(Nothing, XOR rt re2)] ++ invertInstructions le2 ++
363         [(Just l_test, BNE rt registerZero l_exit)] ++ s2' ++
364         [(Just l_assert, BRA l_entry), (Just l_exit, BRA l_test), (Nothing, XORI rt $
            Immediate 1)]
365
366 -- | Code generation for object blocks
367 cgObjectBlock :: TypeName -> SIdentifier -> [SStatement] -> CodeGenerator [(Maybe Label,
    MInstruction)]
368 cgObjectBlock tp n stmt =
369     do rn <- pushRegister n
370     let push = [(Nothing, XOR rn registerSP), (Nothing, SUBI registerSP $ Immediate 1)]
371     malloc <- cgObjectConstruction tp (n, Nothing)
372     stmt' <- concat <$> mapM cgStatement stmt
373     free <- cgObjectDestruction tp (n, Nothing)
374     popRegister
375     return $ push ++ malloc ++ stmt' ++ free ++ invertInstructions push
376
377 -- | Code generation for local blocks
378 cgLocalBlock :: SIdentifier -> SExpression -> [SStatement] -> SExpression -> CodeGenerator [(
    Maybe Label, MInstruction)]
379 cgLocalBlock n e1 stmt e2 =
380     do rn <- pushRegister n
381     (re1, le1, ue1) <- cgExpression e1
382     rt1 <- tempRegister
383     popTempRegister >> ue1
384     stmt' <- concat <$> mapM cgStatement stmt
385     (re2, le2, ue2) <- cgExpression e2
386     rt2 <- tempRegister
387     popTempRegister >> ue2
388     popRegister --rn
389     l <- getUniqueLabel "localBlock"
390     let create re rt = [(Just l, XOR rn registerSP),
391         (Nothing, XOR rt re),
392         (Nothing, EXCH rt registerSP),
393         (Nothing, SUBI registerSP $ Immediate 1)]
394     load = le1 ++ create re1 rt1 ++ invertInstructions le1
395     clear = le2 ++ invertInstructions (create re2 rt2) ++ invertInstructions le2
396     return $ load ++ stmt' ++ clear
397
398 -- | Code generation for calls
399 cgCall :: [(SIdentifier, Maybe SExpression)] -> [(Maybe Label, MInstruction)] -> Register ->
    CodeGenerator [(Maybe Label, MInstruction)]
400 cgCall args jump this =
401     do (ra, la, ua) <- unzip3 <$> mapM loadAddr args
402     sequence_ ua
403     rs <- gets registerStack
404     let rr = (registerThis : map snd rs) \\ (this : ra)
405     store = concatMap push $ rr ++ ra ++ [this]
406     return $ concat la ++ store ++ jump ++ invertInstructions store ++ invertInstructions (
        concat la)
407     where push r = [(Nothing, EXCH r registerSP), (Nothing, SUBI registerSP $ Immediate 1)]
408     loadAddr (n, e) =
409         case e of
410             Nothing -> loadVariableAddress n
411             Just e' -> loadArrayElementVariableAddress n e'

```

```

412
413 -- | Code generation for local calling
414 cgLocalCall :: SIdentifier -> [(SIdentifier, Maybe SExpression)] -> CodeGenerator [(Maybe Label
, MInstruction)]
415 cgLocalCall m args = getMethodLabel m >= \l_m -> cgCall args [(Nothing, BRA l_m)]
registerThis
416
417 -- | Code generation for local uncalling
418 cgLocalUncall :: SIdentifier -> [(SIdentifier, Maybe SExpression)] -> CodeGenerator [(Maybe
Label, MInstruction)]
419 cgLocalUncall m args = getMethodLabel m >= \l_m -> cgCall args [(Nothing, RBRA l_m)]
registerThis
420
421 -- | Returns the type associated with a given identifier
422 getType :: SIdentifier -> CodeGenerator TypeName
423 getType i = gets (symbolTable . saState) >= \st ->
424     case lookup i st of
425         (Just (LocalVariable (ObjectType tp) _)) -> return tp
426         (Just (ClassField (ObjectType tp) _ _)) -> return tp
427         (Just (MethodParameter (ObjectType tp) _)) -> return tp
428         (Just (LocalVariable (ObjectArrayType tp) _)) -> return tp
429         (Just (ClassField (ObjectArrayType tp) _ _)) -> return tp
430         (Just (MethodParameter (ObjectArrayType tp) _)) -> return tp
431         _ -> throwError $ "ICE: Invalid object variable index " ++ show i
432
433 -- | Load the return offset for methods
434 loadMethodAddress :: (SIdentifier, Register) -> MethodName -> CodeGenerator (Register, [(Maybe
Label, MInstruction)])
435 loadMethodAddress (o, ro) m =
436     do rv <- tempRegister
437        rt <- tempRegister
438        rtgt <- tempRegister
439        offsetMacro <- OffsetMacro <$> getType o <*> pure m
440        l <- getUniqueLabel "loadMetAdd"
441        let load = [(Just l, EXCH rv ro),
442                    (Nothing, ADDI rv offsetMacro),
443                    (Nothing, EXCH rt rv),
444                    (Nothing, XOR rtgt rt),
445                    (Nothing, EXCH rt rv),
446                    (Nothing, SUBI rv offsetMacro),
447                    (Nothing, EXCH rv ro)]
448        return (rtgt, load)
449
450 -- | Load address or value needed for calls
451 loadForCall :: (SIdentifier, Maybe SExpression) -> CodeGenerator (Register, [(Maybe Label,
MInstruction)], CodeGenerator ())
452 loadForCall (n, e) = gets (symbolTable . saState) >= \st ->
453     case lookup n st of
454         (Just (ClassField (ObjectArrayType _) _ _)) ->
455             case e of
456                 Just x' -> loadArrayElementVariableValue n x'
457                 _ -> throwError $ "ICE: Invalid variable index " ++ show n
458         (Just ClassField {}) -> loadVariableValue n
459         (Just (LocalVariable (ObjectType _) _)) -> loadVariableValue n
460         (Just (LocalVariable (CopyType _) _)) -> loadVariableValue n
461         (Just (LocalVariable (ObjectArrayType _) _)) ->
462             case e of
463                 Just x' -> loadArrayElementVariableValue n x'
464                 _ -> throwError $ "ICE: Invalid variable index " ++ show n
465         (Just _) -> loadVariableValue n
466         _ -> throwError $ "ICE: Invalid variable index " ++ show n
467
468 -- | Code generation for object calls
469 cgObjectCall :: (SIdentifier, Maybe SExpression) -> MethodName -> [(SIdentifier, Maybe
SExpression)] -> CodeGenerator [(Maybe Label, MInstruction)]
470 cgObjectCall (o, e) m args =

```

```

471 do (ro, lo, uo) <- loadForCall (o, e)
472 rt <- tempRegister
473 (rtgt, loadAddress) <- loadMethodAddress (o, rt) m
474 l_jump <- getUniqueLabel "l_jump"
475 let jp = [(Nothing, SUBI rtgt $ AddressMacro l_jump),
476           (Just l_jump, SWAPBR rtgt),
477           (Nothing, NEG rtgt),
478           (Nothing, ADDI rtgt $ AddressMacro l_jump)]
479 call <- cgCall args jp rt
480 popTempRegister >> popTempRegister >> popTempRegister -- rv, rt & rtgt from loadMethod
481 Addr
482 popTempRegister >> uo
483 let load = lo ++ [(Nothing, XOR rt ro)] ++ loadAddress ++ invertInstructions lo
484 return $ load ++ call ++ invertInstructions load
485 -- | Code generation for object uncalls
486 cgObjectUncall :: (SIdentifier, Maybe SExpression) -> MethodName -> [(SIdentifier, Maybe
487 SExpression)] -> CodeGenerator [(Maybe Label, MInstruction)]
488 cgObjectUncall (o, e) m args =
489 do (ro, lo, uo) <- loadForCall (o, e)
490 rt <- tempRegister
491 (rtgt, loadAddress) <- loadMethodAddress (o, rt) m
492 l_jump <- getUniqueLabel "l_jump"
493 l_rjmp_top <- getUniqueLabel "l_rjmp_top"
494 l_rjmp_bot <- getUniqueLabel "l_rjmp_bot"
495 let jp = [(Nothing, SUBI rtgt $ AddressMacro l_jump),
496           (Just l_rjmp_top, RBRA l_rjmp_bot),
497           (Just l_jump, SWAPBR rtgt),
498           (Nothing, NEG rtgt),
499           (Just l_rjmp_bot, BRA l_rjmp_top),
500           (Nothing, ADDI rtgt $ AddressMacro l_jump)]
501 call <- cgCall args jp rt
502 popTempRegister >> popTempRegister >> popTempRegister -- rv, rt & rtgt from loadMethod
503 Addr
504 popTempRegister >> uo
505 let load = lo ++ [(Nothing, XOR rt ro)] ++ loadAddress ++ invertInstructions lo
506 return $ load ++ call ++ invertInstructions load
507 -- | Code generation for object construction
508 cgObjectConstruction :: TypeName -> (SIdentifier, Maybe SExpression) -> CodeGenerator [(Maybe
509 Label, MInstruction)]
510 cgObjectConstruction tp (n, e) =
511 do (rv, lv, uv) <- case e of
512     Nothing -> loadVariableAddress n
513     Just e' -> loadArrayElementVariableAddress n e'
514 rp <- tempRegister
515 rt <- tempRegister
516 popTempRegister >> popTempRegister
517 l <- getUniqueLabel "obj_con"
518 rs <- gets registerStack
519 let rr = (registerThis : map snd rs) \\ [rp, rt]
520 store = concatMap push rr
521 malloc = [(Just l, ADDI rt $ SizeMacro tp)] ++ push rt ++ push rp
522 lb = l ++ "_bot"
523 setVtable = [(Nothing, XORI rt $ AddressMacro $ "l_" ++ tp ++ "_vt"),
524              (Nothing, EXCH rt rp),
525              (Nothing, ADDI rp ReferenceCounterIndex),
526              (Nothing, XORI rt $ Immediate 1),
527              (Nothing, EXCH rt rp),
528              (Just lb, SUBI rp ReferenceCounterIndex),
529              (Nothing, EXCH rp rv)]
530 uv
531 return $ store ++ malloc ++ [(Nothing, BRA "l_malloc")] ++ invertInstructions malloc ++
532 invertInstructions store ++ lv ++ setVtable ++ invertInstructions lv
533 where push r = [(Nothing, EXCH r registerSP), (Nothing, SUBI registerSP $ Immediate 1)]

```

```

532 -- | Code generation for object destruction
533 cgObjectDestruction :: TypeName -> (SIdentifier, Maybe SExpression) -> CodeGenerator [(Maybe
    Label, MInstruction)]
534 cgObjectDestruction tp (n, e) =
535     do (rp, la, ua) <- case e of
536         Nothing -> loadVariableValue n
537         Just e' -> loadArrayElementVariableValue n e'
538     rt <- tempRegister
539     l <- getUniqueLabel "obj_des"
540     popTempRegister >> ua
541     rs <- gets registerStack
542     let removeVtable = [(Just lt, EXCH rt rp),
543         (Nothing, XORI rt $ AddressMacro $ "l_" ++ tp ++ "_vt"),
544         (Nothing, ADDI rp ReferenceCounterIndex),
545         (Nothing, EXCH rt rp),
546         (Nothing, XORI rt $ Immediate 1),
547         (Nothing, SUBI rp ReferenceCounterIndex)]
548     rr = (registerThis : map snd rs) \\ [rp, rt]
549     store = concatMap push rr
550     free = [(Just l, ADDI rt $ SizeMacro tp)] ++ push rt ++ push rp
551     lt = l ++ "_top"
552     return $ la ++ removeVtable ++ store ++ free ++ [(Nothing, RBRA "l_malloc")] ++
        invertInstructions (la ++ store ++ free)
553     where push r = [(Nothing, EXCH r registerSP), (Nothing, SUBI registerSP $ Immediate 1)]
554
555 -- | Code generation for reference construction
556 cgCopyReference :: (SIdentifier, Maybe SExpression) -> (SIdentifier, Maybe SExpression) ->
    CodeGenerator [(Maybe Label, MInstruction)]
557 cgCopyReference (n, e1) (m, e2) =
558     do (rcp, lp, up) <- case e2 of
559         Nothing -> loadVariableValue m
560         Just e2' -> loadArrayElementVariableValue m e2'
561     (rp, la, ua) <- case e1 of
562         Nothing -> loadVariableValue n
563         Just e1' -> loadArrayElementVariableValue n e1'
564     rt <- tempRegister
565     up >> ua >> popTempRegister
566     l <- getUniqueLabel "copy"
567     let reference = [(Just l, XOR rcp rp),
568         (Nothing, ADDI rp ReferenceCounterIndex),
569         (Nothing, EXCH rt rp),
570         (Nothing, ADDI rt $ Immediate 1),
571         (Nothing, EXCH rt rp),
572         (Nothing, SUBI rp ReferenceCounterIndex)]
573     return $ lp ++ la ++ reference ++ invertInstructions (lp ++ la)
574
575 -- | Code generation for reference destruction
576 cgUnCopyReference :: (SIdentifier, Maybe SExpression) -> (SIdentifier, Maybe SExpression) ->
    CodeGenerator [(Maybe Label, MInstruction)]
577 cgUnCopyReference (n, e1) (m, e2) =
578     do (rcp, la1, ua1) <- case e2 of
579         Nothing -> loadVariableValue m
580         Just e2' -> loadArrayElementVariableValue m e2'
581     (rp, la2, ua2) <- case e1 of
582         Nothing -> loadVariableValue n
583         Just e1' -> loadArrayElementVariableValue n e1'
584     rt <- tempRegister
585     l <- getUniqueLabel "uncopy"
586     ua1 >> ua2 >> popTempRegister
587     let reference = [(Just l, XOR rcp rp),
588         (Nothing, ADDI rp ReferenceCounterIndex),
589         (Nothing, EXCH rt rp),
590         (Nothing, SUBI rt $ Immediate 1),
591         (Nothing, EXCH rt rp),
592         (Nothing, SUBI rp ReferenceCounterIndex)]
593     -- removeRegister (m, rcp)

```

```

594     return $ la1 ++ la2 ++ reference ++ invertInstructions (la1 ++ la2)
595
596 -- | Code generation for array construction
597 cgArrayConstruction :: SExpression -> SIdentifier -> CodeGenerator [(Maybe Label, MInstruction
    )]
598 cgArrayConstruction e n =
599     do (ra, la, ua) <- loadVariableAddress n
600     (re, le, ue) <- cgExpression e
601     rp <- tempRegister
602     rt <- tempRegister
603     popTempRegister >> popTempRegister
604     l <- getUniqueLabel "arr_con"
605     rs <- gets registerStack
606     let rr = (registerThis : map snd rs) \\ [rp, rt]
607     store = le ++ [(Just l, ADDI rt ArrayElementOffset), (Nothing, ADD rt re)] ++
        invertInstructions le ++ concatMap push rr
608     malloc = push rt ++ push rp
609     lb = l ++ "_bot"
610     initArray = la ++ le ++
611         [(Nothing, XOR rt re),
612          (Nothing, EXCH rt rp),
613          (Nothing, ADDI rp ReferenceCounterIndex),
614          (Nothing, XORI rt $ Immediate 1),
615          (Nothing, EXCH rt rp),
616          (Nothing, SUBI rp ReferenceCounterIndex),
617          (Just lb, EXCH rp ra)] ++
        invertInstructions (la ++ le)
618     ue >> ua
619     return $ store ++ malloc ++ [(Nothing, BRA "l_malloc")] ++ invertInstructions (store ++
        malloc) ++ initArray
620
621     where push r = [(Nothing, EXCH r registerSP), (Nothing, SUBI registerSP $ Immediate 1)]
622
623 -- | Code generation for array destruction
624 cgArrayDestruction :: SExpression -> SIdentifier -> CodeGenerator [(Maybe Label, MInstruction)
    ]
625 cgArrayDestruction e n =
626     do (rp, lp, up) <- loadVariableValue n
627     (re, le, ue) <- cgExpression e
628     rt <- tempRegister
629     l <- getUniqueLabel "obj_des"
630     popTempRegister >> ue >> up
631     rs <- gets registerStack
632     let removeArray = [(Just lt, EXCH rt rp),
633                        (Nothing, XOR rt re),
634                        (Nothing, ADDI rp ReferenceCounterIndex),
635                        (Nothing, EXCH rt rp),
636                        (Nothing, XORI rt $ Immediate 1),
637                        (Nothing, SUBI rp ReferenceCounterIndex)]
638     rr = (registerThis : map snd rs) \\ [rp, rt]
639     store = concatMap push rr
640     free = [(Just l, ADDI rt ArrayElementOffset), (Nothing, ADD rt re)] ++ push rt ++
        push rp
641     lt = l ++ "_top"
642     return $ lp ++ le ++ removeArray ++ store ++ free ++ [(Nothing, RBRA "l_malloc")] ++
        invertInstructions (lp ++ le ++ store ++ free)
643     where push r = [(Nothing, EXCH r registerSP), (Nothing, SUBI registerSP $ Immediate 1)]
644
645 -- | Code generation for statements
646 cgStatement :: SStatement -> CodeGenerator [(Maybe Label, MInstruction)]
647 cgStatement (Assign n modop e) = cgAssign n modop e
648 cgStatement (AssignArrElem (n, e1) modop e2) = cgAssignArrElem (n, e1) modop e2
649 cgStatement (Swap (n1, e1) (n2, e2)) = cgSwap (n1, e1) (n2, e2)
650 cgStatement (Conditional e1 s1 s2 e2) = cgConditional e1 s1 s2 e2
651 cgStatement (Loop e1 s1 s2 e2) = cgLoop e1 s1 s2 e2
652 cgStatement (ObjectBlock tp n stmt) = cgObjectBlock tp n stmt
653 cgStatement (LocalBlock _ n e1 stmt e2) = cgLocalBlock n e1 stmt e2

```

```

654 cgStatement (LocalCall m args) = cgLocalCall m args
655 cgStatement (LocalUncall m args) = cgLocalUncall m args
656 cgStatement (ObjectCall o m args) = cgObjectCall o m args
657 cgStatement (ObjectUncall o m args) = cgObjectUncall o m args
658 cgStatement (ObjectConstruction tp n) = cgObjectConstruction tp n
659 cgStatement (ObjectDestruction tp n) = cgObjectDestruction tp n
660 cgStatement Skip = return []
661 cgStatement (CopyReference _ n m) = cgCopyReference n m
662 cgStatement (UnCopyReference _ n m) = cgUnCopyReference n m
663 cgStatement (ArrayConstruction (_, e) n) = cgArrayConstruction e n
664 cgStatement (ArrayDestruction (_, e) n) = cgArrayDestruction e n
665
666 -- | Code generation for methods
667 cgMethod :: (TypeName, SMethodDeclaration) -> CodeGenerator [(Maybe Label, MInstruction)]
668 cgMethod (_, GMDecl m ps body) =
669   do l <- getMethodLabel m
670      rs <- addParameters
671      body' <- concat <$> mapM cgStatement body
672      clearParameters
673      let lt = l ++ "_top"
674          lb = l ++ "_bot"
675          mp = [(Just lt, BRA lb),
676                (Nothing, ADDI registerSP $ Immediate 1),
677                (Nothing, EXCH registerRO registerSP)]
678          ++ concatMap pushParameter rs ++
679          [(Nothing, EXCH registerThis registerSP),
680            (Nothing, SUBI registerSP $ Immediate 1),
681            (Just l, SWAPBR registerRO),
682            (Nothing, NEG registerRO),
683            (Nothing, ADDI registerSP $ Immediate 1),
684            (Nothing, EXCH registerThis registerSP)]
685          ++ invertInstructions (concatMap pushParameter rs) ++
686          [(Nothing, EXCH registerRO registerSP),
687            (Nothing, SUBI registerSP $ Immediate 1)]
688      return $ mp ++ body' ++ [(Just lb, BRA lt)]
689   where addParameters = mapM (pushRegister . (\(GDecl _ p) -> p)) ps
690         clearParameters = replicateM_ (length ps) popRegister
691         pushParameter r = [(Nothing, EXCH r registerSP), (Nothing, SUBI registerSP $
692           Immediate 1)]
693
694 cgMalloc1 :: CodeGenerator [(Maybe Label, MInstruction)]
695 cgMalloc1 =
696   do -- Temp registers needed for malloc
697      r_p <- tempRegister -- Pointer to new obj
698      r_object_size <- tempRegister -- Object size
699      r_counter <- tempRegister -- Free list index
700      r_csize <- tempRegister -- Current cell size
701      rt <- tempRegister
702      rt2 <- tempRegister
703      r_tmp <- tempRegister
704
705   -- Expressions and sub routines
706   (r_e1_outer, l_e1_outer, u_e1_outer) <- cgBinOp Lt r_csize r_object_size
707   (r_e2_outer, l_e2_outer, u_e2_outer) <- cgBinOp Lt r_csize r_object_size
708   (r_fl, l_fl, u_fl) <- loadFreeListAddress r_counter
709   (r_block, l_block, u_block) <- loadHeadAtFreeList r_fl
710   (r_e1_inner, l_e1_inner, u_e1_inner) <- cgBinOp Neq r_block registerZero
711   (r_e2_i1, l_e2_i1, u_e2_i1) <- cgBinOp Neq r_p r_tmp
712   (r_e2_i2, l_e2_i2, u_e2_i2) <- cgBinOp Eq r_tmp registerZero
713   (r_e2_i3, l_e2_i3, u_e2_i3) <- cgBinOp BitOr r_e2_i1 r_e2_i2
714
715   let tmpRegisterList = [rt, rt2, r_tmp, r_e1_outer, r_e2_outer, r_fl, r_block,
716     r_e1_inner, r_e2_i1, r_e2_i2, r_e2_i3]
717
718   -- Update state after evaluating expressions and subroutines
719   u_e2_i3 >> u_e2_i2 >> u_e2_i1 >> u_e1_inner

```

```

718 u_block >> u_fl >> u_e2_outer >> u_el_outer
719 popTempRegister >> popTempRegister >> popTempRegister >> popTempRegister >>
    popTempRegister >> popTempRegister >> popTempRegister
720
721 let l_o_test = "l_o_test"
722     l_o_assert_t = "l_o_assert_true"
723     l_o_test_f = "l_o_test_false"
724     l_o_assert = "l_o_assert"
725     l_i_test = "l_i_test"
726     l_i_assert_t = "l_i_assert_true"
727     l_i_test_f = "l_i_test_false"
728     l_i_assert = "l_i_assert"
729     l_m_top = "l_mallocl_top"
730     l_m_bot = "l_mallocl_bot"
731     l_m_entry = "l_mallocl"
732     malloc = [(Just l_m_top, BRA l_m_bot),           --
733               (Nothing, ADDI registerSP $ Immediate 1),
734               (Nothing, EXCH registerRO registerSP)] -- Pop return offset from
    stack
735     ++ invertInstructions l_fl ++
736     [(Just l_m_entry, SWAPBR registerRO),           -- Mallocl entry/exit point
737      (Nothing, NEG registerRO),                     -- Restore return offset
738      (Nothing, EXCH registerRO registerSP),         -- Push return offset to stack
739      (Nothing, SUBI registerSP $ Immediate 1)]
740     ++ l_fl
741     ++ l_block
742     ++ l_el_outer                                     -- Set r_el -> c_size <
    obj_size
743     ++ [(Nothing, XOR rt r_el_outer)]                -- r_t = r_el_o
744     ++ invertInstructions l_el_outer ++              -- Clear r_el_o
745     [(Just l_o_test, BEQ rt registerZero l_o_test_f),
746      (Nothing, XORI rt $ Immediate 1),              -- Sl_outer start
747      (Nothing, ADDI r_counter $ Immediate 1)]        -- counter++
748     ++ invertInstructions l_block ++
749     [(Nothing, RL r_csize $ Immediate 1)]            -- call double(csize)
750     ++ concatMap pushRegisterToStack tmpRegisterList
751     ++
752     [(Nothing, BRA l_m_entry)]                       -- call malloc1()
753     ++ invertInstructions(concatMap pushRegisterToStack tmpRegisterList)
754     ++
755     [(Nothing, RR r_csize $ Immediate 1),            -- uncall double(csize)
756      (Nothing, SUBI r_counter $ Immediate 1),        -- counter++
757      (Nothing, XORI rt $ Immediate 1),              -- Sl_outer end
758      (Just l_o_assert_t, BRA l_o_assert),
759      (Just l_o_test_f, BRA l_o_test)]
760     ++ l_el_inner ++                                -- Set r_el_i -> r_block != 0
    (S2_OUTER)
761     [(Nothing, XOR rt2 r_el_inner)]                  -- Set rt2 -> r_el_i
762     ++ invertInstructions l_el_inner ++              -- Clear r_el_i
763     [(Just l_i_test, BEQ rt2 registerZero l_i_test_f),
764      (Nothing, XORI rt2 $ Immediate 1),              -- Sl_inner start
765      (Nothing, ADD r_p r_block),                     -- Set address of p to said
    block
766      (Nothing, SUB r_block r_p),                     -- Clear r_block
767      (Nothing, EXCH r_tmp r_p),                     -- Load address of next block
768      (Nothing, EXCH r_tmp r_fl),                     -- Set address of next block
    as head of current free list
769      (Nothing, XOR r_tmp r_p),                       -- Clear address of next block
770      (Nothing, XORI rt2 $ Immediate 1),              -- Sl_inner end
771      (Just l_i_assert_t, BRA l_i_assert),
772      (Just l_i_test_f, BRA l_i_test),
773      (Nothing, ADDI r_counter $ Immediate 1),        -- S2_inner start
774      (Nothing, RL r_csize $ Immediate 1)]            -- call double(csize)
775     ++ concatMap pushRegisterToStack tmpRegisterList ++
776     [(Nothing, BRA l_m_entry)]                       -- call malloc1()
777     ++ invertInstructions(concatMap pushRegisterToStack tmpRegisterList) ++

```



```

778      [(Nothing, RR r_csize $ Immediate 1),      -- uncall double(csize)
779      (Nothing, SUBI r_counter $ Immediate 1),    -- counter -= 1
780      (Nothing, XOR r_tmp r_p),                  -- Copy current address of p
781      (Nothing, EXCH r_tmp r_fl),                -- Store address in current
              free_list
782      (Nothing, ADD r_p r_csize),                -- Set p to other half of the
              block we're splitting
783      (Just l_i_assert, BNE rt2 registerZero l_i_assert_t),
784      (Nothing, EXCH r_tmp r_fl),
785      (Nothing, SUB r_p r_csize)]
786  ++ l_e2_i1                                     -- set r_e2_i1 <- p - csize !=
              free_list[counter]
787  ++ l_e2_i2                                     -- set r_e2_i2 <- free_list[
              counter] = 0
788  ++ l_e2_i3                                     -- set r_e2_i3 <- r_e2_i1 ||
              & r_e2_i2
789  ++ [(Nothing, XOR rt2 r_e2_i3)]                -- Set rt2 -> r_i_2
790  ++ invertInstructions l_e2_i3                  -- Clear r_i_2
791  ++ invertInstructions l_e2_i2
792  ++ invertInstructions l_e2_i1 ++
793  [(Nothing, ADD r_p r_csize),
794   (Nothing, EXCH r_tmp r_fl),                  -- S2_outer end
795   (Just l_o_assert, BNE rt registerZero l_o_assert_t)]
796  ++ l_e2_outer                                -- Set r_e2 -> c_size <
              obj_size
797  ++ [(Nothing, XOR rt r_e2_outer)]              -- r_t = r_e1_o
798  ++ invertInstructions l_e2_outer              -- Clear r_e1_o
799  ++ [(Just l_m_bot, BRA l_m_top)]              -- Go to top
800  return malloc
801  where pushRegisterToStack r = [(Nothing, EXCH r registerSP), (Nothing, SUBI registerSP $
      Immediate 1)]
802
803  cgMalloc :: CodeGenerator [(Maybe Label, MInstruction)]
804  cgMalloc =
805    do rp <- tempRegister -- Pointer to new obj
806    ros <- tempRegister -- Object size
807    rc <- tempRegister -- Free list index
808    rs <- tempRegister -- Current cell size
809    popTempRegister >> popTempRegister >> popTempRegister >> popTempRegister
810    let malloc = [(Just "l_malloc_top", BRA "l_malloc_bot")]
811    ++
812    [(Just "l_malloc", SWAPBR registerRO),
813     (Nothing, NEG registerRO),
814     (Nothing, ADDI rs $ Immediate 2),
815     (Nothing, XOR rc registerZero)]
816    ++ concatMap pop [rp, ros]
817    ++ push registerRO ++
818    [(Nothing, BRA "l_malloc1")]
819    ++ pop registerRO
820    ++ concatMap push [ros, rp] ++
821    [(Nothing, XOR rc registerZero),
822     (Nothing, SUBI rs $ Immediate 2),
823     (Just "l_malloc_bot", BRA "l_malloc_top")]
824  return malloc
825  where pop r = [(Nothing, ADDI registerSP $ Immediate 1), (Nothing, EXCH r registerSP)]
826    push r = invertInstructions (pop r)
827
828  -- | Code generation for virtual tables
829  cgVirtualTables :: CodeGenerator [(Maybe Label, MInstruction)]
830  cgVirtualTables = concat <$> (gets (virtualTables . saState) >>= mapM vtInstructions)
831    where vtInstructions (n, ms) = zip (vtLabel n) <$> mapM vtData ms
832    vtData m = DATA . AddressMacro <$> getMethodLabel m
833    vtLabel n = (Just $ "l_" ++ n ++ "_vt") : repeat Nothing
834
835  -- | Returns the main class label
836  getMainLabel :: CodeGenerator Label

```

```

837 getMainLabel = gets (mainMethod . saState) >=> getMethodLabel
838
839 -- | Fetches the main class from the class analysis state
840 getMainClass :: CodeGenerator TypeName
841 getMainClass = gets (mainClass . caState . saState) >=> \mc ->
842     case mc of
843         (Just tp) -> return tp
844         Nothing -> throwError "ICE: No main method defined"
845
846 -- | Fetches the field of a given type name
847 getFields :: TypeName -> CodeGenerator [VariableDeclaration]
848 getFields tp =
849     do cs <- gets (classes . caState . saState)
850     case lookup tp cs of
851         (Just (GDecl _ _ fs _)) -> return fs
852         Nothing -> throwError $ "ICE: Unknown class " ++ tp
853
854 -- | Code generation for output
855 cgOutput :: TypeName -> CodeGenerator [(Maybe Label, MInstruction)], [(Maybe Label,
856     MInstruction)]
857 cgOutput tp =
858     do mfs <- getFields tp
859     co <- concat <$> mapM cgCopyOutput (zip [1..] mfs)
860     return (map cgStatic mfs, co)
861     where cgStatic (GDecl _ n) = (Just $ "l_r_" ++ n, DATA $ Immediate 0)
862         cgCopyOutput(o, GDecl _ n) =
863             do rt <- tempRegister
864             ra <- tempRegister
865             popTempRegister >> popTempRegister
866             let copy = [ADDI registerThis ReferenceCounterIndex,
867                 ADDI registerThis $ Immediate o,
868                 EXCH rt registerThis,
869                 XORI ra $ AddressMacro $ "l_r_" ++ n,
870                 EXCH rt ra,
871                 XORI ra $ AddressMacro $ "l_r_" ++ n,
872                 SUBI registerThis $ Immediate o,
873                 SUBI registerThis ReferenceCounterIndex]
874             return $ zip (repeat Nothing) copy
875
876 -- | Generates code for the program entry point
877 cgProgram :: SProgram -> CodeGenerator PISA.MProgram
878 cgProgram p =
879     do vt <- cgVirtualTables
880     malloc <- cgMalloc
881     malloc1 <- cgMalloc1
882     rv <- tempRegister -- V table register
883     rb <- tempRegister -- Memory block register
884     popTempRegister >> popTempRegister
885     ms <- concat <$> mapM cgMethod p
886     l_main <- getMainLabel
887     mtp <- getMainClass
888     (out, co) <- cgOutput mtp
889     let mvt = "l_" ++ mtp ++ "_vt"
890     mn = [(Just "start", BRA "top"),
891         (Nothing, START),
892         (Nothing, ADDI registerFLPs ProgramSize), -- Init free list pointer list
893         (Nothing, XOR registerHP registerFLPs), -- Init heap pointer
894         (Nothing, ADDI registerHP FreeListsSize), -- Init space for FLPs list
895         (Nothing, XOR rb registerHP), -- Store address of initial
896             memory block in rb
897         (Nothing, ADDI registerFLPs FreeListsSize), -- Index to end of free lists
898         (Nothing, SUBI registerFLPs $ Immediate 1), -- Index to last element of free
899             lists
900         (Nothing, EXCH rb registerFLPs), -- Store address of first block
901             in last element of free lists
902         (Nothing, ADDI registerFLPs $ Immediate 1), -- Index to end of free lists

```

```

899      (Nothing, SUBI registerFLPs FreeListsSize), -- Index to beginning of free
          lists
900      (Nothing, XOR registerSP registerHP),      -- Init stack pointer 1/2
901      (Nothing, ADDI registerSP StackOffset),    -- Init stack pointer 2/2
902      (Nothing, SUBI registerSP $ SizeMacro mtp), -- Allocate space for main on
          stack
903      (Nothing, XOR registerThis registerSP),    -- Store address of main object
904      (Nothing, XORI rv $ AddressMacro mvt),     -- Store address of vtable in rv
905      (Nothing, EXCH rv registerThis),           -- Add address of vtable to
          stack
906      (Nothing, SUBI registerSP $ Immediate 1),  -- Add address of vtable to
          stack
907      (Nothing, EXCH registerThis registerSP),   -- Push 'this' to stack
908      (Nothing, SUBI registerSP $ Immediate 1),   -- Push 'this' to stack
909      (Nothing, BRA l_main),                     -- Execute main
910      (Nothing, ADDI registerSP $ Immediate 1),   -- Pop 'this'
911      (Nothing, EXCH registerThis registerSP)]   -- Pop 'this'
912      ++ co ++
913      [(Nothing, ADDI registerSP $ Immediate 1),  -- Pop vtable address
914       (Nothing, EXCH rv registerThis),           -- Pop vtable address
915       (Nothing, XORI rv $ AddressMacro mvt),     -- Clear rv
916       (Nothing, XOR registerThis registerSP),   -- Clear 'this'
917       (Nothing, ADDI registerSP $ SizeMacro mtp), -- Deallocate space for main
918       (Nothing, SUBI registerSP StackOffset),    -- Clear stack pointer
919       (Nothing, XOR registerSP registerHP),      -- Clear stack pointer
920       (Nothing, SUBI registerHP FreeListsSize),  -- Reset Heap pointer (For
          pretty output)
921       (Nothing, XOR registerHP registerFLPs),    -- Reset Heap pointer (For
          pretty output)
922       (Nothing, SUBI registerFLPs ProgramSize),  -- Reset Free lists pointer (For
          pretty output)
923       (Just "finish", FINISH)]
924      return $ PISA.GProg $ [(Just "top", BRA "start")] ++ out ++ vt ++ malloc ++ malloc1 ++
          ms ++ mn
925
926
927 -- | Generates code for a program
928 generatePISA :: (SProgram, SASTate) -> Except String (PISA.MProgram, SASTate)
929 generatePISA (p, s) = second saState <$> runStateT (runCG $ cgProgram p) (initialState s)
930
931 showPISAProgram :: (Show a, MonadIO m) => (t, a) -> m ()
932 showPISAProgram (_, s) = pPrint s

```

MacroExpander.hs

```
1 {-# LANGUAGE GeneralizedNewtypeDeriving #-}
2
3 module MacroExpander (expandMacros) where
4
5 import Data.Maybe
6 import Data.List
7
8 import Control.Monad.Reader
9 import Control.Monad.Except
10 import Control.Arrow
11
12 import AST hiding (Program, GProg, Offset)
13 import PISA
14
15 import Debug.Trace (trace, traceShow)
16
17 import ScopeAnalyzer
18 import ClassAnalyzer
19
20 type Size = Integer
21 type Address = Integer
22 type Offset = Integer
23
24 data MState = MState {
25     addressTable :: [(Label, Address)],
26     sizeTable :: [(TypeName, Size)],
27     offsetTable :: [(TypeName, [(MethodName, Offset)])],
28     programSize :: Size,
29     freeListsSize :: Size,
30     stackOffset :: Offset,
31     initialMemoryBlockSize :: Size,
32     referenceCounterIndex :: Offset,
33     arrayElementOffset :: Offset
34 } deriving (Show, Eq)
35
36 newtype MacroExpander a = MacroExpander { runME :: ReaderT MState (Except String) a }
37     deriving (Functor, Applicative, Monad, MonadReader MState, MonadError String)
38
39 -- | Returns the offset table generated from the an indexed virtual table
40 getOffsetTable :: SASTate -> [(TypeName, [(MethodName, Offset)])]
41 getOffsetTable s = map (second (map toOffset)) indexedVT
42     where indexedVT = map (second $ zip [0..]) $ virtualTables s
43           toOffset (i, m) = (getName $ lookup m $ symbolTable s, i)
44           getName (Just (Method _ n)) = n
45           getName _ = error "ICE: Invalid method index"
46
47 -- | Initializes the macro state containing the address, size, offset tables and the program
48     size
49 initialState :: MProgram -> SASTate -> MState
50 initialState (GProg p) s = MState {
51     addressTable = mapMaybe toPair $ zip [0..] p,
52     sizeTable = (classSize . caState) s,
53     offsetTable = getOffsetTable s,
54     programSize = genericLength p,
55     freeListsSize = 10,
56     stackOffset = 2048,
57     initialMemoryBlockSize = 1024,
58     referenceCounterIndex = 1,
59     arrayElementOffset = 2
60 }
61
62     where toPair (a, (Just l, _)) = Just (l, a)
63           toPair _ = Nothing
```

```

63 -- | Returns the address of a given label
64 getAddress :: Label -> MacroExpander Address
65 getAddress l = asks addressTable >>= \at ->
66     case lookup l at of
67         (Just i) -> return i
68         Nothing -> throwError $ "ICE: Unknown label " ++ l
69
70 -- | Returns the size of a given class name
71 getSize :: TypeName -> MacroExpander Size
72 getSize tn = asks sizeTable >>= \st ->
73     case lookup tn st of
74         (Just s) -> return s
75         Nothing -> throwError $ "ICE: Unknown type " ++ tn
76
77 -- | Returns the off set of a method for a given class name and method
78 getOffset :: TypeName -> MethodName -> MacroExpander Offset
79 getOffset tn mn = asks offsetTable >>= \ot ->
80     case lookup tn ot of
81         Nothing -> throwError $ "ICE: Unknown type " ++ tn
82         (Just mo) -> case lookup mn mo of
83             Nothing -> throwError $ "ICE: Unknown method " ++ mn
84             (Just o) -> return o
85
86 -- | Macro definitions
87 meMacro :: Macro -> MacroExpander Integer
88 meMacro (Immediate i) = return i
89 meMacro (AddressMacro l) = getAddress l
90 meMacro (SizeMacro tn) = getSize tn
91 meMacro (OffsetMacro tn mn) = getOffset tn mn
92 meMacro ProgramSize = asks programSize
93 meMacro FreeListsSize = asks freeListsSize
94 meMacro StackOffset = asks stackOffset
95 meMacro InitialMemoryBlockSize = asks initialMemoryBlockSize
96 meMacro ReferenceCounterIndex = asks referenceCounterIndex
97 meMacro ArrayElementOffset = asks arrayElementOffset
98
99 -- | Macro instructions
100 meInstruction :: MInstruction -> MacroExpander Instruction
101 meInstruction (ADD r1 r2) = return $ ADD r1 r2
102 meInstruction (ADDI r m) = ADDI r <$> meMacro m
103 meInstruction (ANDX r1 r2 r3) = return $ ANDX r1 r2 r3
104 meInstruction (ANDIX r1 r2 m) = ANDIX r1 r2 <$> meMacro m
105 meInstruction (NORX r1 r2 r3) = return $ NORX r1 r2 r3
106 meInstruction (NEG r) = return $ NEG r
107 meInstruction (ORX r1 r2 r3) = return $ ORX r1 r2 r3
108 meInstruction (ORIX r1 r2 m) = ORIX r1 r2 <$> meMacro m
109 meInstruction (RL r m) = RL r <$> meMacro m
110 meInstruction (RLV r1 r2) = return $ RLV r1 r2
111 meInstruction (RR r m) = RR r <$> meMacro m
112 meInstruction (RRV r1 r2) = return $ RRV r1 r2
113 meInstruction (SLLX r1 r2 m) = SLLX r1 r2 <$> meMacro m
114 meInstruction (SLLVX r1 r2 r3) = return $ SLLVX r1 r2 r3
115 meInstruction (SRAX r1 r2 m) = SRAX r1 r2 <$> meMacro m
116 meInstruction (SRAVX r1 r2 r3) = return $ SRAVX r1 r2 r3
117 meInstruction (SRLX r1 r2 m) = SRLX r1 r2 <$> meMacro m
118 meInstruction (SRLVX r1 r2 r3) = return $ SRLVX r1 r2 r3
119 meInstruction (SUB r1 r2) = return $ SUB r1 r2
120 meInstruction (XOR r1 r2) = return $ XOR r1 r2
121 meInstruction (XORI r m) = XORI r <$> meMacro m
122 meInstruction (BEQ r1 r2 l) = return $ BEQ r1 r2 l
123 meInstruction (BGEZ r l) = return $ BGEZ r l
124 meInstruction (BGTZ r l) = return $ BGTZ r l
125 meInstruction (BLEZ r l) = return $ BLEZ r l
126 meInstruction (BLTZ r l) = return $ BLTZ r l
127 meInstruction (BNE r1 r2 l) = return $ BNE r1 r2 l
128 meInstruction (BRA l) = return $ BRA l

```

```

129 meInstruction (EXCH r1 r2) = return $ EXCH r1 r2
130 meInstruction (SWAPBR r) = return $ SWAPBR r
131 meInstruction (RBRA l) = return $ RBRA l
132 meInstruction START = return START
133 meInstruction FINISH = return FINISH
134 meInstruction (DATA m) = DATA <$> meMacro m
135 meInstruction (SUBI r m) = SUBI r <$> meMacro m
136
137 -- | Macro Expand a program
138 meProgram :: MProgram -> MacroExpander Program
139 meProgram (GProg p) = GProg <$> mapM expandPair p
140     where expandPair (l, i) = (,) l <$> meInstruction i
141
142 -- | Interface for starting the macro extension process
143 expandMacros :: (MProgram, SASTate) -> Except String Program
144 expandMacros (p, s) = runReaderT (runME $ meProgram p) $ initialState p s

```

ROOPLPPC.hs

```
1 import Control.Monad.Except
2 import System.IO
3 import System.Environment
4
5 import PISA
6 import Parser
7 import ClassAnalyzer
8 import ScopeAnalyzer
9 import TypeChecker
10 import CodeGenerator
11 import MacroExpander
12
13 import Data.List.Split
14
15 type Error = String
16
17 main :: IO ()
18 main =
19     do args <- getArgs
20         when (null args) (error "Supply input filename.\nUsage: ROOPLPPC input.rplpp output.pal\n")
21         when (length args > 2) (error "Too many arguments.\nUsage: ROOPLPPC input.rplpp output.pal\n")
22         handle <- openFile (head args) ReadMode
23         input <- hGetContents handle
24         let output = if length args == 2 then last args else head (splitOn "." (head args)) ++ ".pal"
25         either (hPutStrLn stderr) (writeProgram output) $ compileProgram input
26
27 compileProgram :: String -> Either Error PISA.Program
28 compileProgram s =
29     runExcept $
30     parseString s
31     >>= classAnalysis
32     >>= scopeAnalysis
33     >>= typeCheck
34     >>= generatePISA
35     >>= expandMacros
```

Example Ouput

LinkedList.rplpp

```

1 class Cell
2     Cell next
3     int data
4
5     method constructor(int value)
6         data ^= value
7
8     method append(Cell cell)
9         if next = nil & cell != nil then
10             next <=> cell                // Store as next cell if current cell is end of
11                                     list
12         else skip
13         fi next != nil & cell = nil
14
15         if next != nil then
16             call next::append(cell)      // Recusively search until we reach end of list
17         else skip
18         fi next != nil
19
20 class LinkedList
21     Cell head
22     int listLength
23
24     method insertHead(Cell cell)
25         if head = nil & cell != nil then
26             head <=> cell                // Set cell as head of list if list is empty
27         else skip
28         fi head != nil & cell = nil
29
30     method appendCell(Cell cell)
31         call insertHead(cell)            // Insert as head if empty list
32
33         if head != nil then
34             call head::append(cell)      // Iterate list until we reach the end, then insert
35                                     the node
36         else skip
37         fi head != nil
38
39         listLength += 1                  // Increment lenght
40
41     method prependCell(Cell cell)
42         call insertHead(cell)            // Insert as head if empty list
43
44         if cell != nil & head != nil then
45             call cell::append(head)      // Set cell.next = head. head = nil after execution

```



```

44     else skip
45     fi cell != nil & head = nil
46
47     if cell != nil & head = nil then
48         cell <=> head // Set head = cell. Cell is nil after execution
49     else skip
50     fi cell = nil & head != nil
51
52     listLength += 1 // Increment length
53
54     method length(int result)
55         result ^= listLength
56
57 class Program
58     LinkedList linkedList
59     int sumResult
60     int listLength
61
62     method main()
63         new LinkedList linkedList // Init new linked linkedList
64         listLength += 10
65
66         local int x = 0
67         from x = 0 do
68             skip
69         loop
70             local Cell cell = nil
71             new Cell cell // Instantiate new cell
72             call cell::constructor(x) // Set value of cell
73             call linkedList::appendCell(cell) // Append it to the linkedList
74             delocal Cell cell = nil
75             x += 1
76         until x = listLength
77         delocal int x = listLength

```

LinkedList.pal

```

1  ;; pendulum pal file
2  top:          BRA    start
3  l_r_linkedList: DATA  0
4  l_r_sumResult: DATA  0
5  l_r_listLength: DATA  0
6  l_Program_vt: DATA  972
7  l_LinkedList_vt: DATA  459
8                DATA  562
9                DATA  704
10               DATA  945
11 l_Cell_vt:     DATA  223
12               DATA  252
13 l_malloc_top:  BRA    l_malloc_bot
14 l_malloc:      SWAPBR $2
15               NEG    $2
16               ADDI   $9 2
17               XOR    $8 $0
18               ADDI   $1 1
19               EXCH   $6 $1
20               ADDI   $1 1
21               EXCH   $7 $1
22               EXCH   $2 $1
23               ADDI   $1 -1
24               BRA    l_malloc1
25               ADDI   $1 1
26               EXCH   $2 $1
27               EXCH   $7 $1
28               ADDI   $1 -1
29               EXCH   $6 $1
30               ADDI   $1 -1
31               XOR    $8 $0
32               ADDI   $9 -2
33 l_malloc_bot:  BRA    l_malloc_top
34 l_malloc1_top: BRA    l_malloc1_bot
35               ADDI   $1 1
36               EXCH   $2 $1
37               SUB    $17 $8
38               XOR    $17 $4
39 l_malloc1:     SWAPBR $2
40               NEG    $2
41               EXCH   $2 $1
42               ADDI   $1 -1
43               XOR    $17 $4
44               ADD    $17 $8
45               EXCH   $19 $17
46               XOR    $18 $19
47               EXCH   $19 $17
48               XOR    $13 $9
49               SUB    $13 $7
50 cmp_top_7:      BGEZ   $13 cmp_bot_8
51               XORI   $14 1
52 cmp_bot_8:      BGEZ   $13 cmp_top_7
53               XOR    $10 $14
54 cmp_bot_8_i:    BGEZ   $13
55               cmp_top_7_i
56 cmp_top_7_i:    BGEZ   $13
57               cmp_bot_8_i
58               ADD    $13 $7
59 l_o_test:       XOR    $13 $9
                  BEQ    $10 $0
                  l_o_test_false

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XORI $10 1
ADDI $8 1
EXCH $19 $17
XOR $18 $19
EXCH $19 $17
RL $9 1
EXCH $10 $1
ADDI $1 -1
EXCH $11 $1
ADDI $1 -1
EXCH $12 $1
ADDI $1 -1
EXCH $14 $1
ADDI $1 -1
EXCH $16 $1
ADDI $1 -1
EXCH $17 $1
ADDI $1 -1
EXCH $18 $1
ADDI $1 -1
EXCH $20 $1
ADDI $1 -1
EXCH $21 $1
ADDI $1 -1
EXCH $22 $1
ADDI $1 -1
EXCH $23 $1
ADDI $1 -1
BRA l_malloc1
ADDI $1 1
EXCH $23 $1
ADDI $1 1
EXCH $22 $1
ADDI $1 1
EXCH $20 $1
ADDI $1 1
EXCH $18 $1
ADDI $1 1
EXCH $17 $1
ADDI $1 1
EXCH $16 $1
ADDI $1 1
EXCH $14 $1
ADDI $1 1
EXCH $12 $1
ADDI $1 1
EXCH $11 $1
ADDI $1 1
EXCH $10 $1
RR $9 1
ADDI $8 -1
XORI $10 1
BRA l_o_assert
BRA l_o_test_false
BEQ $18 $0
XORI $20 1
BEQ $18 $0
XOR $11 $20

```

120	cmp_bot_12_i:	BEQ	\$18 \$0	183		EXCH	\$12 \$17
	cmp_top_11_i			184		ADD	\$6 \$9
121		XORI	\$20 1	185	l_i_assert:	BNE	\$11 \$0
122	cmp_top_11_i:	BEQ	\$18 \$0		l_i_assert_true		
	cmp_bot_12_i			186		EXCH	\$12 \$17
123	l_i_test:	BEQ	\$11 \$0	187		SUB	\$6 \$9
	l_i_test_false			188	cmp_top_13:	BEQ	\$6 \$12
124		XORI	\$11 1		cmp_bot_14		
125		ADD	\$6 \$18	189		XORI	\$21 1
126		SUB	\$18 \$6	190	cmp_bot_14:	BEQ	\$6 \$12
127		EXCH	\$12 \$6		cmp_top_13		
128		EXCH	\$12 \$17	191	cmp_top_15:	BNE	\$12 \$0
129		XOR	\$12 \$6		cmp_bot_16		
130		XORI	\$11 1	192		XORI	\$22 1
131	l_i_assert_true:	BRA	l_i_assert	193	cmp_bot_16:	BNE	\$12 \$0
132	l_i_test_false:	BRA	l_i_test		cmp_top_15		
133		ADDI	\$8 1	194		ORX	\$23 \$21 \$22
134		RL	\$9 1	195		XOR	\$11 \$23
135		EXCH	\$10 \$1	196		ORX	\$23 \$21 \$22
136		ADDI	\$1 -1	197	cmp_bot_16_i:	BNE	\$12 \$0
137		EXCH	\$11 \$1		cmp_top_15_i		
138		ADDI	\$1 -1	198		XORI	\$22 1
139		EXCH	\$12 \$1	199	cmp_top_15_i:	BNE	\$12 \$0
140		ADDI	\$1 -1		cmp_bot_16_i		
141		EXCH	\$14 \$1	200	cmp_bot_14_i:	BEQ	\$6 \$12
142		ADDI	\$1 -1		cmp_top_13_i		
143		EXCH	\$16 \$1	201		XORI	\$21 1
144		ADDI	\$1 -1	202	cmp_top_13_i:	BEQ	\$6 \$12
145		EXCH	\$17 \$1		cmp_bot_14_i		
146		ADDI	\$1 -1	203		ADD	\$6 \$9
147		EXCH	\$18 \$1	204		EXCH	\$12 \$17
148		ADDI	\$1 -1	205	l_o_assert:	BNE	\$10 \$0
149		EXCH	\$20 \$1		l_o_assert_true		
150		ADDI	\$1 -1	206		XOR	\$15 \$9
151		EXCH	\$21 \$1	207		SUB	\$15 \$7
152		ADDI	\$1 -1	208	cmp_top_9:	BGEZ	\$15 cmp_bot_10
153		EXCH	\$22 \$1	209		XORI	\$16 1
154		ADDI	\$1 -1	210	cmp_bot_10:	BGEZ	\$15 cmp_top_9
155		EXCH	\$23 \$1	211		XOR	\$10 \$16
156		ADDI	\$1 -1	212	cmp_bot_10_i:	BGEZ	\$15
157		BRA	l_malloc1		cmp_top_9_i		
158		ADDI	\$1 1	213		XORI	\$16 1
159		EXCH	\$23 \$1	214	cmp_top_9_i:	BGEZ	\$15
160		ADDI	\$1 1		cmp_bot_10_i		
161		EXCH	\$22 \$1	215		ADD	\$15 \$7
162		ADDI	\$1 1	216		XOR	\$15 \$9
163		EXCH	\$21 \$1	217	l_malloc1_bot:	BRA	l_malloc1_top
164		ADDI	\$1 1	218	l_constructor_5_top:	BRA	
165		EXCH	\$20 \$1		l_constructor_5_bot		
166		ADDI	\$1 1	219		ADDI	\$1 1
167		EXCH	\$18 \$1	220		EXCH	\$2 \$1
168		ADDI	\$1 1	221		EXCH	\$6 \$1
169		EXCH	\$17 \$1	222		ADDI	\$1 -1
170		ADDI	\$1 1	223		EXCH	\$3 \$1
171		EXCH	\$16 \$1	224		ADDI	\$1 -1
172		ADDI	\$1 1	225	l_constructor_5:	SWAPBR	\$2
173		EXCH	\$14 \$1	226		NEG	\$2
174		ADDI	\$1 1	227		ADDI	\$1 1
175		EXCH	\$12 \$1	228		EXCH	\$3 \$1
176		ADDI	\$1 1	229		ADDI	\$1 1
177		EXCH	\$11 \$1	230		EXCH	\$6 \$1
178		ADDI	\$1 1	231		EXCH	\$2 \$1
179		EXCH	\$10 \$1	232		ADDI	\$1 -1
180		RR	\$9 1	233		ADD	\$7 \$3
181		ADDI	\$8 -1	234		ADDI	\$7 3
182		XOR	\$12 \$6	235		EXCH	\$8 \$7

236		ADDI	\$7 -3		cmp_bot_22_i		
237		SUB	\$7 \$3	290		ADD	\$8 \$3
238		EXCH	\$9 \$6	291		ADDI	\$8 2
239		XOR	\$8 \$9	292		EXCH	\$9 \$8
240		EXCH	\$9 \$6	293		ADDI	\$8 -2
241		ADD	\$7 \$3	294		SUB	\$8 \$3
242		ADDI	\$7 3	295	test_17:	BEQ	\$7 \$0
243		EXCH	\$8 \$7		test_false_19		
244		ADDI	\$7 -3	296		XORI	\$7 1
245		SUB	\$7 \$3	297		ADD	\$8 \$3
246	l_constructor_5_bot:	BRA		298		ADDI	\$8 2
	l_constructor_5_top			299		EXCH	\$9 \$8
247	l_append_6_top:	BRA	l_append_6_bot	300		ADDI	\$8 -2
248		ADDI	\$1 1	301		SUB	\$8 \$3
249		EXCH	\$2 \$1	302		EXCH	\$10 \$6
250		EXCH	\$6 \$1	303	swap_27:	XOR	\$9 \$10
251		ADDI	\$1 -1	304		XOR	\$10 \$9
252		EXCH	\$3 \$1	305		XOR	\$9 \$10
253		ADDI	\$1 -1	306		EXCH	\$10 \$6
254	l_append_6:	SWAPB	\$2	307		ADD	\$8 \$3
255		NEG	\$2	308		ADDI	\$8 2
256		ADDI	\$1 1	309		EXCH	\$9 \$8
257		EXCH	\$3 \$1	310		ADDI	\$8 -2
258		ADDI	\$1 1	311		SUB	\$8 \$3
259		EXCH	\$6 \$1	312		XORI	\$7 1
260		EXCH	\$2 \$1	313	assert_true_18:	BRA	assert_20
261		ADDI	\$1 -1	314	test_false_19:	BRA	test_17
262		ADD	\$8 \$3	315	assert_20:	BNE	\$7 \$0
263		ADDI	\$8 2		assert_true_18		
264		EXCH	\$9 \$8	316		ADD	\$8 \$3
265		ADDI	\$8 -2	317		ADDI	\$8 2
266		SUB	\$8 \$3	318		EXCH	\$9 \$8
267	cmp_top_21:	BNE	\$9 \$0	319		ADDI	\$8 -2
	cmp_bot_22			320		SUB	\$8 \$3
268		XORI	\$10 1	321	cmp_top_28:	BEQ	\$9 \$0
269	cmp_bot_22:	BNE	\$9 \$0		cmp_bot_29		
	cmp_top_21			322		XORI	\$10 1
270		EXCH	\$11 \$6	323	cmp_bot_29:	BEQ	\$9 \$0
271	cmp_top_23:	BEQ	\$11 \$0		cmp_top_28		
	cmp_bot_24			324		EXCH	\$11 \$6
272		XORI	\$12 1	325	cmp_top_30:	BNE	\$11 \$0
273	cmp_bot_24:	BEQ	\$11 \$0		cmp_bot_31		
	cmp_top_23			326		XORI	\$12 1
274		ANDX	\$13 \$10 \$12	327	cmp_bot_31:	BNE	\$11 \$0
275	f_top_25:	BEQ	\$13 \$0		cmp_top_30		
	f_bot_26			328		ANDX	\$13 \$10 \$12
276		XORI	\$14 1	329	f_top_32:	BEQ	\$13 \$0
277	f_bot_26:	BEQ	\$13 \$0		f_bot_33		
	f_top_25			330		XORI	\$14 1
278		XOR	\$7 \$14	331	f_bot_33:	BEQ	\$13 \$0
279	f_bot_26_i:	BEQ	\$13 \$0		f_top_32		
	f_top_25_i			332		XOR	\$7 \$14
280		XORI	\$14 1	333	f_bot_33_i:	BEQ	\$13 \$0
281	f_top_25_i:	BEQ	\$13 \$0		f_top_32_i		
	f_bot_26_i			334		XORI	\$14 1
282		ANDX	\$13 \$10 \$12	335	f_top_32_i:	BEQ	\$13 \$0
283	cmp_bot_24_i:	BEQ	\$11 \$0		f_bot_33_i		
	cmp_top_23_i			336		ANDX	\$13 \$10 \$12
284		XORI	\$12 1	337	cmp_bot_31_i:	BNE	\$11 \$0
285	cmp_top_23_i:	BEQ	\$11 \$0		cmp_top_30_i		
	cmp_bot_24_i			338		XORI	\$12 1
286		EXCH	\$11 \$6	339	cmp_top_30_i:	BNE	\$11 \$0
287	cmp_bot_22_i:	BNE	\$9 \$0		cmp_bot_31_i		
	cmp_top_21_i			340		EXCH	\$11 \$6
288		XORI	\$10 1	341	cmp_bot_29_i:	BEQ	\$9 \$0
289	cmp_top_21_i:	BNE	\$9 \$0		cmp_top_28_i		

342		XORI	\$10 1	398		ADDI	\$13 -397
343	cmp_top_28_i:	BEQ	\$9 \$0	399	l_jmp_43:	SWAPBR	\$13
	cmp_bot_29_i			400		NEG	\$13
344		ADD	\$8 \$3	401		ADDI	\$13 397
345		ADDI	\$8 2	402		ADDI	\$1 1
346		EXCH	\$9 \$8	403		EXCH	\$10 \$1
347		ADDI	\$8 -2	404		ADDI	\$1 1
348		SUB	\$8 \$3	405		EXCH	\$6 \$1
349		ADD	\$8 \$3	406		ADDI	\$1 1
350		ADDI	\$8 2	407		EXCH	\$3 \$1
351		EXCH	\$9 \$8	408		ADD	\$8 \$3
352		ADDI	\$8 -2	409		ADDI	\$8 2
353		SUB	\$8 \$3	410		EXCH	\$9 \$8
354	cmp_top_38:	BEQ	\$9 \$0	411		ADDI	\$8 -2
	cmp_bot_39			412		SUB	\$8 \$3
355		XORI	\$10 1	413		EXCH	\$11 \$10
356	cmp_bot_39:	BEQ	\$9 \$0	414		ADDI	\$11 1
	cmp_top_38			415		EXCH	\$12 \$11
357	f_top_40:	BEQ	\$10 \$0	416		XOR	\$13 \$12
	f_bot_41			417		EXCH	\$12 \$11
358		XORI	\$11 1	418		ADDI	\$11 -1
359	f_bot_41:	BEQ	\$10 \$0	419	loadMetAdd_42_i:	EXCH	\$11 \$10
	f_top_40			420		XOR	\$10 \$9
360		XOR	\$7 \$11	421		ADD	\$8 \$3
361	f_bot_41_i:	BEQ	\$10 \$0	422		ADDI	\$8 2
	f_top_40_i			423		EXCH	\$9 \$8
362		XORI	\$11 1	424		ADDI	\$8 -2
363	f_top_40_i:	BEQ	\$10 \$0	425		SUB	\$8 \$3
	f_bot_41_i			426		XORI	\$7 1
364	cmp_bot_39_i:	BEQ	\$9 \$0	427	assert_true_35:	BRA	assert_37
	cmp_top_38_i			428	test_false_36:	BRA	test_34
365		XORI	\$10 1	429	assert_37:	BNE	\$7 \$0
366	cmp_top_38_i:	BEQ	\$9 \$0		assert_true_35		
	cmp_bot_39_i			430		ADD	\$8 \$3
367		ADD	\$8 \$3	431		ADDI	\$8 2
368		ADDI	\$8 2	432		EXCH	\$9 \$8
369		EXCH	\$9 \$8	433		ADDI	\$8 -2
370		ADDI	\$8 -2	434		SUB	\$8 \$3
371		SUB	\$8 \$3	435	cmp_top_44:	BEQ	\$9 \$0
372	test_34:	BEQ	\$7 \$0		cmp_bot_45		
	test_false_36			436		XORI	\$10 1
373		XORI	\$7 1	437	cmp_bot_45:	BEQ	\$9 \$0
374		ADD	\$8 \$3		cmp_top_44		
375		ADDI	\$8 2	438	f_top_46:	BEQ	\$10 \$0
376		EXCH	\$9 \$8		f_bot_47		
377		ADDI	\$8 -2	439		XORI	\$11 1
378		SUB	\$8 \$3	440	f_bot_47:	BEQ	\$10 \$0
379		XOR	\$10 \$9		f_top_46		
380	loadMetAdd_42:	EXCH	\$11 \$10	441		XOR	\$7 \$11
381		ADDI	\$11 1	442	f_bot_47_i:	BEQ	\$10 \$0
382		EXCH	\$12 \$11		f_top_46_i		
383		XOR	\$13 \$12	443		XORI	\$11 1
384		EXCH	\$12 \$11	444	f_top_46_i:	BEQ	\$10 \$0
385		ADDI	\$11 -1		f_bot_47_i		
386		EXCH	\$11 \$10	445	cmp_bot_45_i:	BEQ	\$9 \$0
387		ADD	\$8 \$3		cmp_top_44_i		
388		ADDI	\$8 2	446		XORI	\$10 1
389		EXCH	\$9 \$8	447	cmp_top_44_i:	BEQ	\$9 \$0
390		ADDI	\$8 -2		cmp_bot_45_i		
391		SUB	\$8 \$3	448		ADD	\$8 \$3
392		EXCH	\$3 \$1	449		ADDI	\$8 2
393		ADDI	\$1 -1	450		EXCH	\$9 \$8
394		EXCH	\$6 \$1	451		ADDI	\$8 -2
395		ADDI	\$1 -1	452		SUB	\$8 \$3
396		EXCH	\$10 \$1	453	l_append_6_bot:	BRA	l_append_6_top
397		ADDI	\$1 -1	454	l_insertHead_1_top:	BRA	

455	l_insertHead_1_bot		507		ADDI	\$8 -2
456		ADDI	508		SUB	\$8 \$3
457		EXCH	509		EXCH	\$10 \$6
458		EXCH	510	swap_58:	XOR	\$9 \$10
459		ADDI	511		XOR	\$10 \$9
460		EXCH	512		XOR	\$9 \$10
461	l_insertHead_1:	ADDI	513		EXCH	\$10 \$6
462		SWAPBR	514		ADD	\$8 \$3
463		NEG	515		ADDI	\$8 2
464		ADDI	516		EXCH	\$9 \$8
465		EXCH	517		ADDI	\$8 -2
466		ADDI	518		SUB	\$8 \$3
467		EXCH	519		XORI	\$7 1
468		EXCH	520	assert_true_49:	BRA	assert_51
469		ADDI	521	test_false_50:	BRA	test_48
470		ADD	522	assert_51:	BNE	\$7 \$0
471		ADDI		assert_true_49		
472		EXCH	523		ADD	\$8 \$3
473		ADDI	524		ADDI	\$8 2
474	cmp_top_52:	SUB	525		EXCH	\$9 \$8
475	cmp_bot_53	BNE	526		ADDI	\$8 -2
476			527		SUB	\$8 \$3
477		XORI	528	cmp_top_59:	BEQ	\$9 \$0
478	cmp_bot_53:	BNE		cmp_bot_60		
479	cmp_top_52		529		XORI	\$10 1
480		EXCH	530	cmp_bot_60:	BEQ	\$9 \$0
481	cmp_top_54:	BEQ		cmp_top_59		
482	cmp_bot_55		531		EXCH	\$11 \$6
483		XORI	532	cmp_top_61:	BNE	\$11 \$0
484	cmp_bot_55:	BEQ		cmp_bot_62		
485	cmp_top_54		533		XORI	\$12 1
486		ANDX	534	cmp_bot_62:	BNE	\$11 \$0
487	f_top_56:	BEQ		cmp_top_61		
488	f_bot_57		535		ANDX	\$13 \$10 \$12
489		XORI	536	f_top_63:	BEQ	\$13 \$0
490	f_bot_57:	BEQ		f_bot_64		
491	f_top_56		537		XORI	\$14 1
492		XOR	538	f_bot_64:	BEQ	\$13 \$0
493	f_bot_57_i:	BEQ		f_top_63		
494	f_top_56_i		539		XOR	\$7 \$14
495		XORI	540	f_bot_64_i:	BEQ	\$13 \$0
496	f_bot_57_i	BEQ		f_top_63_i		
497		ANDX	541		XORI	\$14 1
498	cmp_bot_55_i:	BEQ	542	f_top_63_i:	BEQ	\$13 \$0
499	cmp_top_54_i:			f_bot_64_i		
500	cmp_bot_55_i		543		ANDX	\$13 \$10 \$12
501		XORI	544	cmp_bot_62_i:	BNE	\$11 \$0
502	test_48:	BEQ		cmp_top_61_i		
503	test_false_50		545		XORI	\$12 1
504		EXCH	546	cmp_top_61_i:	BNE	\$11 \$0
505				cmp_bot_62_i		
506		XORI	547		EXCH	\$11 \$6
		ADD	548	cmp_bot_60_i:	BEQ	\$9 \$0
		ADDI		cmp_top_59_i		
		EXCH	549		XORI	\$10 1
			550	cmp_top_59_i:	BEQ	\$9 \$0
		ADD		cmp_bot_60_i		
		ADDI	551		ADD	\$8 \$3
		SUB	552		ADDI	\$8 2
		BEQ	553		EXCH	\$9 \$8
			554		ADDI	\$8 -2
		XORI	555		SUB	\$8 \$3
		ADD	556	l_insertHead_1_bot:	BRA	
		ADDI		l_insertHead_1_top		
		EXCH	557	l_appendCell_2_top:	BRA	
				l_appendCell_2_bot		

558		ADDI	\$1 1	615		XOR	\$13 \$12
559		EXCH	\$2 \$1	616		EXCH	\$12 \$11
560		EXCH	\$6 \$1	617		ADDI	\$11 -1
561		ADDI	\$1 -1	618		EXCH	\$11 \$10
562		EXCH	\$3 \$1	619		ADD	\$8 \$3
563		ADDI	\$1 -1	620		ADDI	\$8 2
564	l_appendCell_2:	SWAPBR	\$2	621		EXCH	\$9 \$8
565		NEG	\$2	622		ADDI	\$8 -2
566		ADDI	\$1 1	623		SUB	\$8 \$3
567		EXCH	\$3 \$1	624		EXCH	\$3 \$1
568		ADDI	\$1 1	625		ADDI	\$1 -1
569		EXCH	\$6 \$1	626		EXCH	\$6 \$1
570		EXCH	\$2 \$1	627		ADDI	\$1 -1
571		ADDI	\$1 -1	628		EXCH	\$10 \$1
572		EXCH	\$6 \$1	629		ADDI	\$1 -1
573		ADDI	\$1 -1	630		ADDI	\$13 -629
574		EXCH	\$3 \$1	631	l_jump_74:	SWAPBR	\$13
575		ADDI	\$1 -1	632		NEG	\$13
576		BRA	l_insertHead_433	633		ADDI	\$13 629
577		ADDI	\$1 1	634		ADDI	\$1 1
578		EXCH	\$3 \$1	635		EXCH	\$10 \$1
579		ADDI	\$1 1	636		ADDI	\$1 1
580		EXCH	\$6 \$1	637		EXCH	\$6 \$1
581		ADD	\$8 \$3	638		ADDI	\$1 1
582		ADDI	\$8 2	639		EXCH	\$3 \$1
583		EXCH	\$9 \$8	640		ADD	\$8 \$3
584		ADDI	\$8 -2	641		ADDI	\$8 2
585		SUB	\$8 \$3	642		EXCH	\$9 \$8
586	cmp_top_69:	BEQ	\$9 \$0	643		ADDI	\$8 -2
	cmp_bot_70			644		SUB	\$8 \$3
587		XORI	\$10 1	645		EXCH	\$11 \$10
588	cmp_bot_70:	BEQ	\$9 \$0	646		ADDI	\$11 1
	cmp_top_69			647		EXCH	\$12 \$11
589	f_top_71:	BEQ	\$10 \$0	648		XOR	\$13 \$12
	f_bot_72			649		EXCH	\$12 \$11
590		XORI	\$11 1	650		ADDI	\$11 -1
591	f_bot_72:	BEQ	\$10 \$0	651	loadMetAdd_73_i:	EXCH	\$11 \$10
	f_top_71			652		XOR	\$10 \$9
592		XOR	\$7 \$11	653		ADD	\$8 \$3
593	f_bot_72_i:	BEQ	\$10 \$0	654		ADDI	\$8 2
	f_top_71_i			655		EXCH	\$9 \$8
594		XORI	\$11 1	656		ADDI	\$8 -2
595	f_top_71_i:	BEQ	\$10 \$0	657		SUB	\$8 \$3
	f_bot_72_i			658		XORI	\$7 1
596	cmp_bot_70_i:	BEQ	\$9 \$0	659	assert_true_66:	BRA	assert_68
	cmp_top_69_i			660	test_false_67:	BRA	test_65
597		XORI	\$10 1	661	assert_68:	BNE	\$7 \$0
598	cmp_top_69_i:	BEQ	\$9 \$0		assert_true_66		
	cmp_bot_70_i			662		ADD	\$8 \$3
599		ADD	\$8 \$3	663		ADDI	\$8 2
600		ADDI	\$8 2	664		EXCH	\$9 \$8
601		EXCH	\$9 \$8	665		ADDI	\$8 -2
602		ADDI	\$8 -2	666		SUB	\$8 \$3
603		SUB	\$8 \$3	667	cmp_top_75:	BEQ	\$9 \$0
604	test_65:	BEQ	\$7 \$0		cmp_bot_76		
	test_false_67			668		XORI	\$10 1
605		XORI	\$7 1	669	cmp_bot_76:	BEQ	\$9 \$0
606		ADD	\$8 \$3		cmp_top_75		
607		ADDI	\$8 2	670	f_top_77:	BEQ	\$10 \$0
608		EXCH	\$9 \$8		f_bot_78		
609		ADDI	\$8 -2	671		XORI	\$11 1
610		SUB	\$8 \$3	672	f_bot_78:	BEQ	\$10 \$0
611		XOR	\$10 \$9		f_top_77		
612	loadMetAdd_73:	EXCH	\$11 \$10	673		XOR	\$7 \$11
613		ADDI	\$11 1	674	f_bot_78_i:	BEQ	\$10 \$0
614		EXCH	\$12 \$11		f_top_77_i		

675		XORI	\$11 1	733		XORI	\$12 1
676	f_top_77_i:	BEQ	\$10 \$0	734	cmp_bot_86:	BEQ	\$11 \$0
	f_bot_78_i				cmp_top_85		
677	cmp_bot_76_i:	BEQ	\$9 \$0	735		ANDX	\$13 \$9 \$12
	cmp_top_75_i			736	f_top_87:	BEQ	\$13 \$0
678		XORI	\$10 1		f_bot_88		
679	cmp_top_75_i:	BEQ	\$9 \$0	737		XORI	\$14 1
	cmp_bot_76_i			738	f_bot_88:	BEQ	\$13 \$0
680		ADD	\$8 \$3		f_top_87		
681		ADDI	\$8 2	739		XOR	\$7 \$14
682		EXCH	\$9 \$8	740	f_bot_88_i:	BEQ	\$13 \$0
683		ADDI	\$8 -2		f_top_87_i		
684		SUB	\$8 \$3	741		XORI	\$14 1
685		ADD	\$7 \$3	742	f_top_87_i:	BEQ	\$13 \$0
686		ADDI	\$7 3		f_bot_88_i		
687		EXCH	\$8 \$7	743		ANDX	\$13 \$9 \$12
688		ADDI	\$7 -3	744	cmp_bot_86_i:	BEQ	\$11 \$0
689		SUB	\$7 \$3		cmp_top_85_i		
690		XORI	\$9 1	745		XORI	\$12 1
691		ADD	\$8 \$9	746	cmp_top_85_i:	BEQ	\$11 \$0
692		XORI	\$9 1		cmp_bot_86_i		
693		ADD	\$7 \$3	747		ADD	\$10 \$3
694		ADDI	\$7 3	748		ADDI	\$10 2
695		EXCH	\$8 \$7	749		EXCH	\$11 \$10
696		ADDI	\$7 -3	750		ADDI	\$10 -2
697		SUB	\$7 \$3	751		SUB	\$10 \$3
698	l_appendCell_2_bot:	BRA		752	cmp_bot_84_i:	BEQ	\$8 \$0
	l_appendCell_2_top				cmp_top_83_i		
699	l_prependCell_3_top:	BRA		753		XORI	\$9 1
	l_prependCell_3_bot			754	cmp_top_83_i:	BEQ	\$8 \$0
700		ADDI	\$1 1		cmp_bot_84_i		
701		EXCH	\$2 \$1	755		EXCH	\$8 \$6
702		EXCH	\$6 \$1	756	test_79:	BEQ	\$7 \$0
703		ADDI	\$1 -1		test_false_81		
704		EXCH	\$3 \$1	757		XORI	\$7 1
705		ADDI	\$1 -1	758		EXCH	\$8 \$6
706	l_prependCell_3:	SWAPBR	\$2	759		XOR	\$9 \$8
707		NEG	\$2	760	loadMetAdd_89:	EXCH	\$10 \$9
708		ADDI	\$1 1	761		ADDI	\$10 1
709		EXCH	\$3 \$1	762		EXCH	\$11 \$10
710		ADDI	\$1 1	763		XOR	\$12 \$11
711		EXCH	\$6 \$1	764		EXCH	\$11 \$10
712		EXCH	\$2 \$1	765		ADDI	\$10 -1
713		ADDI	\$1 -1	766		EXCH	\$10 \$9
714		EXCH	\$6 \$1	767		EXCH	\$8 \$6
715		ADDI	\$1 -1	768		ADD	\$13 \$3
716		EXCH	\$3 \$1	769		ADDI	\$13 2
717		ADDI	\$1 -1	770		EXCH	\$3 \$1
718		BRA	l_insertHead_471	771		ADDI	\$1 -1
719		ADDI	\$1 1	772		EXCH	\$6 \$1
720		EXCH	\$3 \$1	773		ADDI	\$1 -1
721		ADDI	\$1 1	774		EXCH	\$13 \$1
722		EXCH	\$6 \$1	775		ADDI	\$1 -1
723		EXCH	\$8 \$6	776		EXCH	\$9 \$1
724	cmp_top_83:	BEQ	\$8 \$0	777		ADDI	\$1 -1
	cmp_bot_84			778		ADDI	\$12 -777
725		XORI	\$9 1	779	l_jump_90:	SWAPBR	\$12
726	cmp_bot_84:	BEQ	\$8 \$0	780		NEG	\$12
	cmp_top_83			781		ADDI	\$12 777
727		ADD	\$10 \$3	782		ADDI	\$1 1
728		ADDI	\$10 2	783		EXCH	\$9 \$1
729		EXCH	\$11 \$10	784		ADDI	\$1 1
730		ADDI	\$10 -2	785		EXCH	\$13 \$1
731		SUB	\$10 \$3	786		ADDI	\$1 1
732	cmp_top_85:	BEQ	\$11 \$0	787		EXCH	\$6 \$1
	cmp_bot_86			788		ADDI	\$1 1

789		EXCH	\$3 \$1	841		XORI	\$9 1
790		ADDI	\$13 -2	842	cmp_bot_102:	BEQ	\$8 \$0
791		SUB	\$13 \$3		cmp_top_101		
792		EXCH	\$8 \$6	843		ADD	\$10 \$3
793		EXCH	\$10 \$9	844		ADDI	\$10 2
794		ADDI	\$10 1	845		EXCH	\$11 \$10
795		EXCH	\$11 \$10	846		ADDI	\$10 -2
796		XOR	\$12 \$11	847		SUB	\$10 \$3
797		EXCH	\$11 \$10	848	cmp_top_103:	BNE	\$11 \$0
798		ADDI	\$10 -1		cmp_bot_104		
799	loadMetAdd_89_i:	EXCH	\$10 \$9	849		XORI	\$12 1
800		XOR	\$9 \$8	850	cmp_bot_104:	BNE	\$11 \$0
801		EXCH	\$8 \$6		cmp_top_103		
802		XORI	\$7 1	851		ANDX	\$13 \$9 \$12
803	assert_true_80:	BRA	assert_82	852	f_top_105:	BEQ	\$13 \$0
804	test_false_81:	BRA	test_79		f_bot_106		
805	assert_82:	BNE	\$7 \$0	853		XORI	\$14 1
	assert_true_80			854	f_bot_106:	BEQ	\$13 \$0
806		EXCH	\$8 \$6		f_top_105		
807	cmp_top_91:	BEQ	\$8 \$0	855		XOR	\$7 \$14
	cmp_bot_92			856	f_bot_106_i:	BEQ	\$13 \$0
808		XORI	\$9 1		f_top_105_i		
809	cmp_bot_92:	BEQ	\$8 \$0	857		XORI	\$14 1
	cmp_top_91			858	f_top_105_i:	BEQ	\$13 \$0
810		ADD	\$10 \$3		f_bot_106_i		
811		ADDI	\$10 2	859		ANDX	\$13 \$9 \$12
812		EXCH	\$11 \$10	860	cmp_bot_104_i:	BNE	\$11 \$0
813		ADDI	\$10 -2		cmp_top_103_i		
814		SUB	\$10 \$3	861		XORI	\$12 1
815	cmp_top_93:	BNE	\$11 \$0	862	cmp_top_103_i:	BNE	\$11 \$0
	cmp_bot_94				cmp_bot_104_i		
816		XORI	\$12 1	863		ADD	\$10 \$3
817	cmp_bot_94:	BNE	\$11 \$0	864		ADDI	\$10 2
	cmp_top_93			865		EXCH	\$11 \$10
818		ANDX	\$13 \$9 \$12	866		ADDI	\$10 -2
819	f_top_95:	BEQ	\$13 \$0	867		SUB	\$10 \$3
	f_bot_96			868	cmp_bot_102_i:	BEQ	\$8 \$0
820		XORI	\$14 1		cmp_top_101_i		
821	f_bot_96:	BEQ	\$13 \$0	869		XORI	\$9 1
	f_top_95			870	cmp_top_101_i:	BEQ	\$8 \$0
822		XOR	\$7 \$14		cmp_bot_102_i		
823	f_bot_96_i:	BEQ	\$13 \$0	871		EXCH	\$8 \$6
	f_top_95_i			872	test_97:	BEQ	\$7 \$0
824		XORI	\$14 1		test_false_99		
825	f_top_95_i:	BEQ	\$13 \$0	873		XORI	\$7 1
	f_bot_96_i			874		EXCH	\$8 \$6
826		ANDX	\$13 \$9 \$12	875		ADD	\$9 \$3
827	cmp_bot_94_i:	BNE	\$11 \$0	876		ADDI	\$9 2
	cmp_top_93_i			877		EXCH	\$10 \$9
828		XORI	\$12 1	878		ADDI	\$9 -2
829	cmp_top_93_i:	BNE	\$11 \$0	879		SUB	\$9 \$3
	cmp_bot_94_i			880	swap_107:	XOR	\$8 \$10
830		ADD	\$10 \$3	881		XOR	\$10 \$8
831		ADDI	\$10 2	882		XOR	\$8 \$10
832		EXCH	\$11 \$10	883		ADD	\$9 \$3
833		ADDI	\$10 -2	884		ADDI	\$9 2
834		SUB	\$10 \$3	885		EXCH	\$10 \$9
835	cmp_bot_92_i:	BEQ	\$8 \$0	886		ADDI	\$9 -2
	cmp_top_91_i			887		SUB	\$9 \$3
836		XORI	\$9 1	888		EXCH	\$8 \$6
837	cmp_top_91_i:	BEQ	\$8 \$0	889		XORI	\$7 1
	cmp_bot_92_i			890	assert_true_98:	BRA	assert_100
838		EXCH	\$8 \$6	891	test_false_99:	BRA	test_97
839		EXCH	\$8 \$6	892	assert_100:	BNE	\$7 \$0
840	cmp_top_101:	BEQ	\$8 \$0		assert_true_98		
	cmp_bot_102			893		EXCH	\$8 \$6

894	cmp_top_108:	BNE	\$8 \$0	947	l_length_4:	SWAPBR	\$2
	cmp_bot_109			948		NEG	\$2
895		XORI	\$9 1	949		ADDI	\$1 1
896	cmp_bot_109:	BNE	\$8 \$0	950		EXCH	\$3 \$1
	cmp_top_108			951		ADDI	\$1 1
897		ADD	\$10 \$3	952		EXCH	\$6 \$1
898		ADDI	\$10 2	953		EXCH	\$2 \$1
899		EXCH	\$11 \$10	954		ADDI	\$1 -1
900		ADDI	\$10 -2	955		EXCH	\$7 \$6
901		SUB	\$10 \$3	956		ADD	\$8 \$3
902	cmp_top_110:	BEQ	\$11 \$0	957		ADDI	\$8 3
	cmp_bot_111			958		EXCH	\$9 \$8
903		XORI	\$12 1	959		ADDI	\$8 -3
904	cmp_bot_111:	BEQ	\$11 \$0	960		SUB	\$8 \$3
	cmp_top_110			961		XOR	\$7 \$9
905		ANDX	\$13 \$9 \$12	962		ADD	\$8 \$3
906	f_top_112:	BEQ	\$13 \$0	963		ADDI	\$8 3
	f_bot_113			964		EXCH	\$9 \$8
907		XORI	\$14 1	965		ADDI	\$8 -3
908	f_bot_113:	BEQ	\$13 \$0	966		SUB	\$8 \$3
	f_top_112			967		EXCH	\$7 \$6
909		XOR	\$7 \$14	968	l_length_4_bot:	BRA	l_length_4_top
910	f_bot_113_i:	BEQ	\$13 \$0	969	l_main_0_top:	BRA	l_main_0_bot
	f_top_112_i			970		ADDI	\$1 1
911		XORI	\$14 1	971		EXCH	\$2 \$1
912	f_top_112_i:	BEQ	\$13 \$0	972		EXCH	\$3 \$1
	f_bot_113_i			973		ADDI	\$1 -1
913		ANDX	\$13 \$9 \$12	974	l_main_0:	SWAPBR	\$2
914	cmp_bot_111_i:	BEQ	\$11 \$0	975		NEG	\$2
	cmp_top_110_i			976		ADDI	\$1 1
915		XORI	\$12 1	977		EXCH	\$3 \$1
916	cmp_top_110_i:	BEQ	\$11 \$0	978		EXCH	\$2 \$1
	cmp_bot_111_i			979		ADDI	\$1 -1
917		ADD	\$10 \$3	980		EXCH	\$3 \$1
918		ADDI	\$10 2	981		ADDI	\$1 -1
919		EXCH	\$11 \$10	982	obj_con_114:	ADDI	\$8 4
920		ADDI	\$10 -2	983		EXCH	\$8 \$1
921		SUB	\$10 \$3	984		ADDI	\$1 -1
922	cmp_bot_109_i:	BNE	\$8 \$0	985		EXCH	\$7 \$1
	cmp_top_108_i			986		ADDI	\$1 -1
923		XORI	\$9 1	987		BRA	l_malloc
924	cmp_top_108_i:	BNE	\$8 \$0	988		ADDI	\$1 1
	cmp_bot_109_i			989		EXCH	\$7 \$1
925		EXCH	\$8 \$6	990		ADDI	\$1 1
926		ADD	\$7 \$3	991		EXCH	\$8 \$1
927		ADDI	\$7 3	992	obj_con_114_i:	ADDI	\$8 -4
928		EXCH	\$8 \$7	993		ADDI	\$1 1
929		ADDI	\$7 -3	994		EXCH	\$3 \$1
930		SUB	\$7 \$3	995		ADD	\$6 \$3
931		XORI	\$9 1	996		ADDI	\$6 2
932		ADD	\$8 \$9	997		XORI	\$8 5
933		XORI	\$9 1	998		EXCH	\$8 \$7
934		ADD	\$7 \$3	999		ADDI	\$7 1
935		ADDI	\$7 3	1000		XORI	\$8 1
936		EXCH	\$8 \$7	1001		EXCH	\$8 \$7
937		ADDI	\$7 -3	1002	obj_con_114_bot:	ADDI	\$7 -1
938		SUB	\$7 \$3	1003		EXCH	\$7 \$6
939	l_prependCell_3_bot:	BRA		1004		ADDI	\$6 -2
	l_prependCell_3_top			1005		SUB	\$6 \$3
940	l_length_4_top:	BRA	l_length_4_bot	1006		ADD	\$6 \$3
941		ADDI	\$1 1	1007		ADDI	\$6 4
942		EXCH	\$2 \$1	1008		EXCH	\$7 \$6
943		EXCH	\$6 \$1	1009		ADDI	\$6 -4
944		ADDI	\$1 -1	1010		SUB	\$6 \$3
945		EXCH	\$3 \$1	1011		XORI	\$8 10
946		ADDI	\$1 -1	1012		ADD	\$7 \$8

1013		XORI	\$8 10	1062		ADDI	\$9 -4
1014		ADD	\$6 \$3	1063		SUB	\$9 \$3
1015		ADDI	\$6 4	1064		EXCH	\$8 \$6
1016		EXCH	\$7 \$6	1065	test_116:	BNE	\$7 \$0 exit_118
1017		ADDI	\$6 -4	1066	localBlock_128:	XOR	\$8 \$1
1018		SUB	\$6 \$3	1067		XOR	\$9 \$0
1019	localBlock_133:	XOR	\$6 \$1	1068		EXCH	\$9 \$1
1020		XOR	\$7 \$0	1069		ADDI	\$1 -1
1021		EXCH	\$7 \$1	1070		EXCH	\$3 \$1
1022		ADDI	\$1 -1	1071		ADDI	\$1 -1
1023		XORI	\$7 1	1072		EXCH	\$8 \$1
1024	entry_115:	BEQ	\$7 \$0	1073		ADDI	\$1 -1
	assert_117			1074		EXCH	\$6 \$1
1025		EXCH	\$8 \$6	1075		ADDI	\$1 -1
1026	cmp_top_119:	BNE	\$8 \$0	1076	obj_con_123:	ADDI	\$10 4
	cmp_bot_120			1077		EXCH	\$10 \$1
1027		XORI	\$9 1	1078		ADDI	\$1 -1
1028	cmp_bot_120:	BNE	\$8 \$0	1079		EXCH	\$9 \$1
	cmp_top_119			1080		ADDI	\$1 -1
1029	f_top_121:	BEQ	\$9 \$0	1081		BRA	l_malloc
	f_bot_122			1082		ADDI	\$1 1
1030		XORI	\$10 1	1083		EXCH	\$9 \$1
1031	f_bot_122:	BEQ	\$9 \$0	1084		ADDI	\$1 1
	f_top_121			1085		EXCH	\$10 \$1
1032		XOR	\$7 \$10	1086	obj_con_123_i:	ADDI	\$10 -4
1033	f_bot_122_i:	BEQ	\$9 \$0	1087		ADDI	\$1 1
	f_top_121_i			1088		EXCH	\$6 \$1
1034		XORI	\$10 1	1089		ADDI	\$1 1
1035	f_top_121_i:	BEQ	\$9 \$0	1090		EXCH	\$8 \$1
	f_bot_122_i			1091		ADDI	\$1 1
1036	cmp_bot_120_i:	BNE	\$8 \$0	1092		EXCH	\$3 \$1
	cmp_top_119_i			1093		XORI	\$10 9
1037		XORI	\$9 1	1094		EXCH	\$10 \$9
1038	cmp_top_119_i:	BNE	\$8 \$0	1095		ADDI	\$9 1
	cmp_bot_120_i			1096		XORI	\$10 1
1039		EXCH	\$8 \$6	1097		EXCH	\$10 \$9
1040		EXCH	\$8 \$6	1098	obj_con_123_bot:	ADDI	\$9 -1
1041		ADD	\$9 \$3	1099		EXCH	\$9 \$8
1042		ADDI	\$9 4	1100		EXCH	\$9 \$8
1043		EXCH	\$10 \$9	1101		XOR	\$10 \$9
1044		ADDI	\$9 -4	1102	loadMetAdd_124:	EXCH	\$11 \$10
1045		SUB	\$9 \$3	1103		ADDI	\$11 0
1046	cmp_top_129:	BNE	\$8 \$10	1104		EXCH	\$12 \$11
	cmp_bot_130			1105		XOR	\$13 \$12
1047		XORI	\$11 1	1106		EXCH	\$12 \$11
1048	cmp_bot_130:	BNE	\$8 \$10	1107		ADDI	\$11 0
	cmp_top_129			1108		EXCH	\$11 \$10
1049	f_top_131:	BEQ	\$11 \$0	1109		EXCH	\$9 \$8
	f_bot_132			1110		EXCH	\$3 \$1
1050		XORI	\$12 1	1111		ADDI	\$1 -1
1051	f_bot_132:	BEQ	\$11 \$0	1112		EXCH	\$8 \$1
	f_top_131			1113		ADDI	\$1 -1
1052		XOR	\$7 \$12	1114		EXCH	\$6 \$1
1053	f_bot_132_i:	BEQ	\$11 \$0	1115		ADDI	\$1 -1
	f_top_131_i			1116		EXCH	\$10 \$1
1054		XORI	\$12 1	1117		ADDI	\$1 -1
1055	f_top_131_i:	BEQ	\$11 \$0	1118		ADDI	\$13 -1117
	f_bot_132_i			1119	l_jmp_125:	SWAPBR	\$13
1056	cmp_bot_130_i:	BNE	\$8 \$10	1120		NEG	\$13
	cmp_top_129_i			1121		ADDI	\$13 1117
1057		XORI	\$11 1	1122		ADDI	\$1 1
1058	cmp_top_129_i:	BNE	\$8 \$10	1123		EXCH	\$10 \$1
	cmp_bot_130_i			1124		ADDI	\$1 1
1059		ADD	\$9 \$3	1125		EXCH	\$6 \$1
1060		ADDI	\$9 4	1126		ADDI	\$1 1
1061		EXCH	\$10 \$9	1127		EXCH	\$8 \$1

1128		ADDI	\$1 1	1194		ADDI	\$9 -2
1129		EXCH	\$3 \$1	1195		SUB	\$9 \$3
1130		EXCH	\$9 \$8	1196		ADDI	\$1 1
1131		EXCH	\$11 \$10	1197		EXCH	\$9 \$1
1132		ADDI	\$11 0	1198		XOR	\$9 \$0
1133		EXCH	\$12 \$11	1199	localBlock_128_i:	XOR	\$8 \$1
1134		XOR	\$13 \$12	1200		EXCH	\$8 \$6
1135		EXCH	\$12 \$11	1201		XORI	\$9 1
1136		ADDI	\$11 0	1202		ADD	\$8 \$9
1137	loadMetAdd_124_i:	EXCH	\$11 \$10	1203		XORI	\$9 1
1138		XOR	\$10 \$9	1204		EXCH	\$8 \$6
1139		EXCH	\$9 \$8	1205	assert_117:	BRA	entry_115
1140		ADD	\$9 \$3	1206	exit_118:	BRA	test_116
1141		ADDI	\$9 2	1207		XORI	\$7 1
1142		EXCH	\$10 \$9	1208		ADD	\$7 \$3
1143		ADDI	\$9 -2	1209		ADDI	\$7 4
1144		SUB	\$9 \$3	1210		EXCH	\$8 \$7
1145		XOR	\$11 \$10	1211		ADDI	\$7 -4
1146	loadMetAdd_126:	EXCH	\$12 \$11	1212		SUB	\$7 \$3
1147		ADDI	\$12 1	1213		ADDI	\$1 1
1148		EXCH	\$13 \$12	1214		EXCH	\$9 \$1
1149		XOR	\$14 \$13	1215		XOR	\$9 \$8
1150		EXCH	\$13 \$12	1216	localBlock_133_i:	XOR	\$6 \$1
1151		ADDI	\$12 -1	1217		ADD	\$7 \$3
1152		EXCH	\$12 \$11	1218		ADDI	\$7 4
1153		ADD	\$9 \$3	1219		EXCH	\$8 \$7
1154		ADDI	\$9 2	1220		ADDI	\$7 -4
1155		EXCH	\$10 \$9	1221		SUB	\$7 \$3
1156		ADDI	\$9 -2	1222	l_main_0_bot:	BRA	l_main_0_top
1157		SUB	\$9 \$3	1223	start:	BRA	top
1158		EXCH	\$3 \$1	1224		START	
1159		ADDI	\$1 -1	1225		ADDI	\$4 1279
1160		EXCH	\$6 \$1	1226		XOR	\$5 \$4
1161		ADDI	\$1 -1	1227		ADDI	\$5 10
1162		EXCH	\$8 \$1	1228		XOR	\$7 \$5
1163		ADDI	\$1 -1	1229		ADDI	\$4 10
1164		EXCH	\$11 \$1	1230		ADDI	\$4 -1
1165		ADDI	\$1 -1	1231		EXCH	\$7 \$4
1166		ADDI	\$14 -1165	1232		ADDI	\$4 1
1167	l_jump_127:	SWAPBR	\$14	1233		ADDI	\$4 -10
1168		NEG	\$14	1234		XOR	\$1 \$5
1169		ADDI	\$14 1165	1235		ADDI	\$1 2048
1170		ADDI	\$1 1	1236		ADDI	\$1 -8
1171		EXCH	\$11 \$1	1237		XOR	\$3 \$1
1172		ADDI	\$1 1	1238		XORI	\$6 4
1173		EXCH	\$8 \$1	1239		EXCH	\$6 \$3
1174		ADDI	\$1 1	1240		ADDI	\$1 -1
1175		EXCH	\$6 \$1	1241		EXCH	\$3 \$1
1176		ADDI	\$1 1	1242		ADDI	\$1 -1
1177		EXCH	\$3 \$1	1243		BRA	l_main_0
1178		ADD	\$9 \$3	1244		ADDI	\$1 1
1179		ADDI	\$9 2	1245		EXCH	\$3 \$1
1180		EXCH	\$10 \$9	1246		ADDI	\$3 1
1181		ADDI	\$9 -2	1247		ADDI	\$3 1
1182		SUB	\$9 \$3	1248		EXCH	\$6 \$3
1183		EXCH	\$12 \$11	1249		XORI	\$7 1
1184		ADDI	\$12 1	1250		EXCH	\$6 \$7
1185		EXCH	\$13 \$12	1251		XORI	\$7 1
1186		XOR	\$14 \$13	1252		ADDI	\$3 -1
1187		EXCH	\$13 \$12	1253		ADDI	\$3 -1
1188		ADDI	\$12 -1	1254		ADDI	\$3 1
1189	loadMetAdd_126_i:	EXCH	\$12 \$11	1255		ADDI	\$3 2
1190		XOR	\$11 \$10	1256		EXCH	\$6 \$3
1191		ADD	\$9 \$3	1257		XORI	\$7 2
1192		ADDI	\$9 2	1258		EXCH	\$6 \$7
1193		EXCH	\$10 \$9	1259		XORI	\$7 2

1260	ADDI	\$3	-2	1271	EXCH	\$6	\$3
1261	ADDI	\$3	-1	1272	XORI	\$6	4
1262	ADDI	\$3	1	1273	XOR	\$3	\$1
1263	ADDI	\$3	3	1274	ADDI	\$1	8
1264	EXCH	\$6	\$3	1275	ADDI	\$1	-2048
1265	XORI	\$7	3	1276	XOR	\$1	\$5
1266	EXCH	\$6	\$7	1277	ADDI	\$5	-10
1267	XORI	\$7	3	1278	XOR	\$5	\$4
1268	ADDI	\$3	-3	1279	ADDI	\$4	-1279
1269	ADDI	\$3	-1	1280	FINISH		
1270	ADDI	\$1	1				

finish:

BinaryTree.rplpp

```
1 class Node
2     Node left
3     Node right
4     int value
5
6     method setValue(int newValue)
7         value ^= newValue
8
9     method insertNode(Node node, int nodeValue)
10        if nodeValue < value then                // Determine if we insert left or
11            right                                right
12            if left = nil & node != nil then
13                left <=> node                    // If open left node, store here
14            else skip
15            fi left != nil & node = nil
16
17            if left != nil then
18                call left::insertNode(node, nodeValue) // If current node has left, continue
19                iterating
20            else skip
21            fi left != nil
22        else
23            if right = nil & node != nil then
24                right <=> node                    // If open right node spot, store here
25            else skip
26            fi right != nil & node = nil
27
28            if right != nil then
29                call right::insertNode(node, nodeValue) // If current node has, continue
30                searching
31            else skip
32            fi right != nil
33        fi nodeValue < value
34
35    method getSum(int result)
36        result += value                        // Add the value of this node to the sum
37
38        if left != nil then
39            call left::getSum(result)           // If we have a left child, follow that path
40        else skip
41        fi left != nil                          // Else, skip
42
43        if right != nil then
44            call right::getSum(result)           // If we have a right child, follow that path
45        else skip
46        fi right != nil                          // Else, skip
47
48    method mirror()
49        left <=> right                        // Swap left and right children
50
51        if left = nil then skip
52        else call left::mirror()                // Recursively swap children if left != nil
53        fi left = nil
54
55        if right = nil then skip
56        else call right::mirror()                // Recursively swap children if right != nil
57        fi right = nil
58
59 class Tree
60     Node root
61
62     method insertNode(Node node, int value)
63         if root = nil & node != nil then
```

```

61         root <=> node
62     else skip
63     fi root != nil & node = nil
64
65     if root != nil then
66         call root::insertNode(node, value)
67     else skip
68     fi root != nil
69
70     method sum(int result)
71     if root != nil then
72         call root::getSum(result)
73     else skip
74     fi root != nil
75
76     method mirror()
77     if root != nil then
78         call root::mirror()
79     else skip
80     fi root != nil
81
82 class Program
83     int sumResult
84     Tree tree
85     int nodeCount
86
87     method main()
88         new Tree tree
89         nodeCount += 3
90
91         local int x = 0
92         from x = 0 do
93             skip
94         loop
95             local Node node = nil
96             new Node node // Init new node
97             call node::setValue(x) // Set node value
98             call tree::insertNode(node, x) // Insert node in tree
99             delocal Node node = nil
100             x += 1
101         until x = nodeCount
102         delocal int x = nodeCount
103
104         call tree::sum(sumResult)
105         call tree::mirror()

```

BinaryTree.pal

```

1  ;; pendulum pal file
2  top:                BRA    start                61
3  l_r_sumResult:      DATA  0                    62
4  l_r_tree:           DATA  0                    63
5  l_r_nodeCount:      DATA  0                    64
6  l_Program_vt:       DATA  1644                 65
7  l_Tree_vt:          DATA  1201                 66
8                      DATA  1414                 67
9                      DATA  1532                 68
10 l_Node_vt:          DATA  224                   69
11                      DATA  255                   70
12                      DATA  727                   71
13                      DATA  962                   72
14 l_malloc_top:       BRA    l_malloc_bot          73
15 l_malloc:           SWAPBR $2                    74
16                     NEG    $2                    75
17                     ADDI   $9 2                   76
18                     XOR    $8 $0                  77
19                     ADDI   $1 1                   78
20                     EXCH   $6 $1                  79
21                     ADDI   $1 1                   80
22                     EXCH   $7 $1                  81
23                     EXCH   $2 $1                  82
24                     ADDI   $1 -1                  83
25                     BRA    l_malloc1             84
26                     ADDI   $1 1                   85
27                     EXCH   $2 $1                  86
28                     EXCH   $7 $1                  87
29                     ADDI   $1 -1                  88
30                     EXCH   $6 $1                  89
31                     ADDI   $1 -1                  90
32                     XOR    $8 $0                  91
33                     ADDI   $9 -2                  92
34 l_malloc_bot:       BRA    l_malloc_top          93
35 l_malloc1_top:      BRA    l_malloc1_bot         94
36                     ADDI   $1 1                   95
37                     EXCH   $2 $1                  96
38                     SUB    $17 $8                 97
39                     XOR    $17 $4                 98
40 l_malloc1:          SWAPBR $2                    99
41                     NEG    $2                    100
42                     EXCH   $2 $1                  101
43                     ADDI   $1 -1                  102
44                     XOR    $17 $4                 103
45                     ADD    $17 $8                 104
46                     EXCH   $19 $17                105
47                     XOR    $18 $19                106
48                     EXCH   $19 $17                107
49                     XOR    $13 $9                 108
50                     SUB    $13 $7                 109
51 cmp_top_8:          BGEZ   $13 cmp_bot_9         110
52                     XORI   $14 1                  111
53 cmp_bot_9:          BGEZ   $13 cmp_top_8         112
54                     XOR    $10 $14                113
55 cmp_bot_9_i:        BGEZ   $13                  114
56                     cmp_top_8_i                  115
57 cmp_top_8_i:        BGEZ   $13                  116
58                     cmp_bot_9_i                  117
59                     ADD    $13 $7                 118
60 l_o_test:           XOR    $13 $9                 119
61                     BEQ    $10 $0                 120

```

```

l_o_test_false
XORI    $10 1
ADDI    $8 1
EXCH    $19 $17
XOR     $18 $19
EXCH    $19 $17
RL      $9 1
EXCH    $10 $1
ADDI    $1 -1
EXCH    $11 $1
ADDI    $1 -1
EXCH    $12 $1
ADDI    $1 -1
EXCH    $14 $1
ADDI    $1 -1
EXCH    $16 $1
ADDI    $1 -1
EXCH    $17 $1
ADDI    $1 -1
EXCH    $18 $1
ADDI    $1 -1
EXCH    $20 $1
ADDI    $1 -1
EXCH    $21 $1
ADDI    $1 -1
EXCH    $22 $1
ADDI    $1 -1
EXCH    $23 $1
ADDI    $1 -1
BRA     l_malloc1
ADDI    $1 1
EXCH    $23 $1
ADDI    $1 1
EXCH    $22 $1
ADDI    $1 1
EXCH    $21 $1
ADDI    $1 1
EXCH    $20 $1
ADDI    $1 1
EXCH    $18 $1
ADDI    $1 1
EXCH    $17 $1
ADDI    $1 1
EXCH    $16 $1
ADDI    $1 1
EXCH    $14 $1
ADDI    $1 1
EXCH    $12 $1
ADDI    $1 1
EXCH    $11 $1
ADDI    $1 1
RR      $9 1
ADDI    $8 -1
XORI    $10 1
BRA     l_o_assert
BRA     l_o_test
BEQ     $18 $0
XORI    $20 1
BEQ     $18 $0
l_o_assert_true:
l_o_test_false:
cmp_top_12:
cmp_bot_13
XORI    $20 1
BEQ     $18 $0
cmp_bot_13:
cmp_top_12

```


120		XOR	\$11 \$20	183		XOR	\$12 \$6
121	cmp_bot_13_i:	BEQ	\$18 \$0	184		EXCH	\$12 \$17
	cmp_top_12_i			185		ADD	\$6 \$9
122		XORI	\$20 1	186	l_i_assert:	BNE	\$11 \$0
123	cmp_top_12_i:	BEQ	\$18 \$0		l_i_assert_true		
	cmp_bot_13_i			187		EXCH	\$12 \$17
124	l_i_test:	BEQ	\$11 \$0	188		SUB	\$6 \$9
	l_i_test_false			189	cmp_top_14:	BEQ	\$6 \$12
125		XORI	\$11 1		cmp_bot_15		
126		ADD	\$6 \$18	190		XORI	\$21 1
127		SUB	\$18 \$6	191	cmp_bot_15:	BEQ	\$6 \$12
128		EXCH	\$12 \$6		cmp_top_14		
129		EXCH	\$12 \$17	192	cmp_top_16:	BNE	\$12 \$0
130		XOR	\$12 \$6		cmp_bot_17		
131		XORI	\$11 1	193		XORI	\$22 1
132	l_i_assert_true:	BRA	l_i_assert	194	cmp_bot_17:	BNE	\$12 \$0
133	l_i_test_false:	BRA	l_i_test		cmp_top_16		
134		ADDI	\$8 1	195		ORX	\$23 \$21 \$22
135		RL	\$9 1	196		XOR	\$11 \$23
136		EXCH	\$10 \$1	197		ORX	\$23 \$21 \$22
137		ADDI	\$1 -1	198	cmp_bot_17_i:	BNE	\$12 \$0
138		EXCH	\$11 \$1		cmp_top_16_i		
139		ADDI	\$1 -1	199		XORI	\$22 1
140		EXCH	\$12 \$1	200	cmp_top_16_i:	BNE	\$12 \$0
141		ADDI	\$1 -1		cmp_bot_17_i		
142		EXCH	\$14 \$1	201	cmp_bot_15_i:	BEQ	\$6 \$12
143		ADDI	\$1 -1		cmp_top_14_i		
144		EXCH	\$16 \$1	202		XORI	\$21 1
145		ADDI	\$1 -1	203	cmp_top_14_i:	BEQ	\$6 \$12
146		EXCH	\$17 \$1		cmp_bot_15_i		
147		ADDI	\$1 -1	204		ADD	\$6 \$9
148		EXCH	\$18 \$1	205		EXCH	\$12 \$17
149		ADDI	\$1 -1	206	l_o_assert:	BNE	\$10 \$0
150		EXCH	\$20 \$1		l_o_assert_true		
151		ADDI	\$1 -1	207		XOR	\$15 \$9
152		EXCH	\$21 \$1	208		SUB	\$15 \$7
153		ADDI	\$1 -1	209	cmp_top_10:	BGEZ	\$15 cmp_bot_11
154		EXCH	\$22 \$1	210		XORI	\$16 1
155		ADDI	\$1 -1	211	cmp_bot_11:	BGEZ	\$15 cmp_top_10
156		EXCH	\$23 \$1	212		XOR	\$10 \$16
157		ADDI	\$1 -1	213	cmp_bot_11_i:	BGEZ	\$15
158		BRA	l_malloc1		cmp_top_10_i		
159		ADDI	\$1 1	214		XORI	\$16 1
160		EXCH	\$23 \$1	215	cmp_top_10_i:	BGEZ	\$15
161		ADDI	\$1 1		cmp_bot_11_i		
162		EXCH	\$22 \$1	216		ADD	\$15 \$7
163		ADDI	\$1 1	217		XOR	\$15 \$9
164		EXCH	\$21 \$1	218	l_malloc1_bot:	BRA	l_malloc1_top
165		ADDI	\$1 1	219	l_setValue_4_top:	BRA	
166		EXCH	\$20 \$1		l_setValue_4_bot		
167		ADDI	\$1 1	220		ADDI	\$1 1
168		EXCH	\$18 \$1	221		EXCH	\$2 \$1
169		ADDI	\$1 1	222		EXCH	\$6 \$1
170		EXCH	\$17 \$1	223		ADDI	\$1 -1
171		ADDI	\$1 1	224		EXCH	\$3 \$1
172		EXCH	\$16 \$1	225		ADDI	\$1 -1
173		ADDI	\$1 1	226	l_setValue_4:	SWAPBR	\$2
174		EXCH	\$14 \$1	227		NEG	\$2
175		ADDI	\$1 1	228		ADDI	\$1 1
176		EXCH	\$12 \$1	229		EXCH	\$3 \$1
177		ADDI	\$1 1	230		ADDI	\$1 1
178		EXCH	\$11 \$1	231		EXCH	\$6 \$1
179		ADDI	\$1 1	232		EXCH	\$2 \$1
180		EXCH	\$10 \$1	233		ADDI	\$1 -1
181		RR	\$9 1	234		ADD	\$7 \$3
182		ADDI	\$8 -1	235		ADDI	\$7 4

236		EXCH	\$8 \$7	294		SUB	\$10 \$3
237		ADDI	\$7 -4	295		EXCH	\$9 \$7
238		SUB	\$7 \$3	296	test_18:	BEQ	\$8 \$0
239		EXCH	\$9 \$6		test_false_20		
240		XOR	\$8 \$9	297		XORI	\$8 1
241		EXCH	\$9 \$6	298		ADD	\$10 \$3
242		ADD	\$7 \$3	299		ADDI	\$10 2
243		ADDI	\$7 4	300		EXCH	\$11 \$10
244		EXCH	\$8 \$7	301		ADDI	\$10 -2
245		ADDI	\$7 -4	302		SUB	\$10 \$3
246		SUB	\$7 \$3	303	cmp_top_30:	BNE	\$11 \$0
247	l_setValue_4_bot:	BRA			cmp_bot_31		
	l_setValue_4_top			304		XORI	\$12 1
248	l_insertNode_5_top:	BRA		305	cmp_bot_31:	BNE	\$11 \$0
	l_insertNode_5_bot				cmp_top_30		
249		ADDI	\$1 1	306		EXCH	\$13 \$6
250		EXCH	\$2 \$1	307	cmp_top_32:	BEQ	\$13 \$0
251		EXCH	\$6 \$1		cmp_bot_33		
252		ADDI	\$1 -1	308		XORI	\$14 1
253		EXCH	\$7 \$1	309	cmp_bot_33:	BEQ	\$13 \$0
254		ADDI	\$1 -1		cmp_top_32		
255		EXCH	\$3 \$1	310		ANDX	\$15 \$12 \$14
256		ADDI	\$1 -1	311	f_top_34:	BEQ	\$15 \$0
257	l_insertNode_5:	SWAPBR	\$2		f_bot_35		
258		NEG	\$2	312		XORI	\$16 1
259		ADDI	\$1 1	313	f_bot_35:	BEQ	\$15 \$0
260		EXCH	\$3 \$1		f_top_34		
261		ADDI	\$1 1	314		XOR	\$9 \$16
262		EXCH	\$7 \$1	315	f_bot_35_i:	BEQ	\$15 \$0
263		ADDI	\$1 1		f_top_34_i		
264		EXCH	\$6 \$1	316		XORI	\$16 1
265		EXCH	\$2 \$1	317	f_top_34_i:	BEQ	\$15 \$0
266		ADDI	\$1 -1		f_bot_35_i		
267		EXCH	\$9 \$7	318		ANDX	\$15 \$12 \$14
268		ADD	\$10 \$3	319	cmp_bot_33_i:	BEQ	\$13 \$0
269		ADDI	\$10 4		cmp_top_32_i		
270		EXCH	\$11 \$10	320		XORI	\$14 1
271		ADDI	\$10 -4	321	cmp_top_32_i:	BEQ	\$13 \$0
272		SUB	\$10 \$3		cmp_bot_33_i		
273		XOR	\$12 \$9	322		EXCH	\$13 \$6
274		SUB	\$12 \$11	323	cmp_bot_31_i:	BNE	\$11 \$0
275	cmp_top_22:	BGEZ	\$12 cmp_bot_23		cmp_top_30_i		
276		XORI	\$13 1	324		XORI	\$12 1
277	cmp_bot_23:	BGEZ	\$12 cmp_top_22	325	cmp_top_30_i:	BNE	\$11 \$0
278	f_top_24:	BEQ	\$13 \$0		cmp_bot_31_i		
	f_bot_25			326		ADD	\$10 \$3
279		XORI	\$14 1	327		ADDI	\$10 2
280	f_bot_25:	BEQ	\$13 \$0	328		EXCH	\$11 \$10
	f_top_24			329		ADDI	\$10 -2
281		XOR	\$8 \$14	330		SUB	\$10 \$3
282	f_bot_25_i:	BEQ	\$13 \$0	331	test_26:	BEQ	\$9 \$0
	f_top_24_i				test_false_28		
283		XORI	\$14 1	332		XORI	\$9 1
284	f_top_24_i:	BEQ	\$13 \$0	333		ADD	\$10 \$3
	f_bot_25_i			334		ADDI	\$10 2
285	cmp_bot_23_i:	BGEZ	\$12	335		EXCH	\$11 \$10
	cmp_top_22_i			336		ADDI	\$10 -2
286		XORI	\$13 1	337		SUB	\$10 \$3
287	cmp_top_22_i:	BGEZ	\$12	338		EXCH	\$12 \$6
	cmp_bot_23_i			339	swap_36:	XOR	\$11 \$12
288		ADD	\$12 \$11	340		XOR	\$12 \$11
289		XOR	\$12 \$9	341		XOR	\$11 \$12
290		ADD	\$10 \$3	342		EXCH	\$12 \$6
291		ADDI	\$10 4	343		ADD	\$10 \$3
292		EXCH	\$11 \$10	344		ADDI	\$10 2
293		ADDI	\$10 -4	345		EXCH	\$11 \$10

346		ADDI	\$10 -2		f_top_49		
347		SUB	\$10 \$3	396		XOR	\$9 \$13
348		XORI	\$9 1	397	f_bot_50_i:	BEQ	\$12 \$0
349	assert_true_27:	BRA	assert_29		f_top_49_i		
350	test_false_28:	BRA	test_26	398		XORI	\$13 1
351	assert_29:	BNE	\$9 \$0	399	f_top_49_i:	BEQ	\$12 \$0
	assert_true_27				f_bot_50_i		
352		ADD	\$10 \$3	400	cmp_bot_48_i:	BEQ	\$11 \$0
353		ADDI	\$10 2		cmp_top_47_i		
354		EXCH	\$11 \$10	401		XORI	\$12 1
355		ADDI	\$10 -2	402	cmp_top_47_i:	BEQ	\$11 \$0
356		SUB	\$10 \$3		cmp_bot_48_i		
357	cmp_top_37:	BEQ	\$11 \$0	403		ADD	\$10 \$3
	cmp_bot_38			404		ADDI	\$10 2
358		XORI	\$12 1	405		EXCH	\$11 \$10
359	cmp_bot_38:	BEQ	\$11 \$0	406		ADDI	\$10 -2
	cmp_top_37			407		SUB	\$10 \$3
360		EXCH	\$13 \$6	408	test_43:	BEQ	\$9 \$0
361	cmp_top_39:	BNE	\$13 \$0		test_false_45		
	cmp_bot_40			409		XORI	\$9 1
362		XORI	\$14 1	410		ADD	\$10 \$3
363	cmp_bot_40:	BNE	\$13 \$0	411		ADDI	\$10 2
	cmp_top_39			412		EXCH	\$11 \$10
364		ANDX	\$15 \$12 \$14	413		ADDI	\$10 -2
365	f_top_41:	BEQ	\$15 \$0	414		SUB	\$10 \$3
	f_bot_42			415		XOR	\$12 \$11
366		XORI	\$16 1	416	loadMetAdd_51:	EXCH	\$13 \$12
367	f_bot_42:	BEQ	\$15 \$0	417		ADDI	\$13 1
	f_top_41			418		EXCH	\$14 \$13
368		XOR	\$9 \$16	419		XOR	\$15 \$14
369	f_bot_42_i:	BEQ	\$15 \$0	420		EXCH	\$14 \$13
	f_top_41_i			421		ADDI	\$13 -1
370		XORI	\$16 1	422		EXCH	\$13 \$12
371	f_top_41_i:	BEQ	\$15 \$0	423		ADD	\$10 \$3
	f_bot_42_i			424		ADDI	\$10 2
372		ANDX	\$15 \$12 \$14	425		EXCH	\$11 \$10
373	cmp_bot_40_i:	BNE	\$13 \$0	426		ADDI	\$10 -2
	cmp_top_39_i			427		SUB	\$10 \$3
374		XORI	\$14 1	428		EXCH	\$3 \$1
375	cmp_top_39_i:	BNE	\$13 \$0	429		ADDI	\$1 -1
	cmp_bot_40_i			430		EXCH	\$6 \$1
376		EXCH	\$13 \$6	431		ADDI	\$1 -1
377	cmp_bot_38_i:	BEQ	\$11 \$0	432		EXCH	\$7 \$1
	cmp_top_37_i			433		ADDI	\$1 -1
378		XORI	\$12 1	434		EXCH	\$12 \$1
379	cmp_top_37_i:	BEQ	\$11 \$0	435		ADDI	\$1 -1
	cmp_bot_38_i			436		ADDI	\$15 -435
380		ADD	\$10 \$3	437	l_jmp_52:	SWAPBR	\$15
381		ADDI	\$10 2	438		NEG	\$15
382		EXCH	\$11 \$10	439		ADDI	\$15 435
383		ADDI	\$10 -2	440		ADDI	\$1 1
384		SUB	\$10 \$3	441		EXCH	\$12 \$1
385		ADD	\$10 \$3	442		ADDI	\$1 1
386		ADDI	\$10 2	443		EXCH	\$7 \$1
387		EXCH	\$11 \$10	444		ADDI	\$1 1
388		ADDI	\$10 -2	445		EXCH	\$6 \$1
389		SUB	\$10 \$3	446		ADDI	\$1 1
390	cmp_top_47:	BEQ	\$11 \$0	447		EXCH	\$3 \$1
	cmp_bot_48			448		ADD	\$10 \$3
391		XORI	\$12 1	449		ADDI	\$10 2
392	cmp_bot_48:	BEQ	\$11 \$0	450		EXCH	\$11 \$10
	cmp_top_47			451		ADDI	\$10 -2
393	f_top_49:	BEQ	\$12 \$0	452		SUB	\$10 \$3
	f_bot_50			453		EXCH	\$13 \$12
394		XORI	\$13 1	454		ADDI	\$13 1
395	f_bot_50:	BEQ	\$12 \$0	455		EXCH	\$14 \$13

456		XOR	\$15 \$14	509	f_top_65:	BEQ	\$15 \$0
457		EXCH	\$14 \$13		f_bot_66		
458		ADDI	\$13 -1	510		XORI	\$16 1
459	loadMetAdd_51_i:	EXCH	\$13 \$12	511	f_bot_66:	BEQ	\$15 \$0
460		XOR	\$12 \$11		f_top_65		
461		ADD	\$10 \$3	512		XOR	\$9 \$16
462		ADDI	\$10 2	513	f_bot_66_i:	BEQ	\$15 \$0
463		EXCH	\$11 \$10		f_top_65_i		
464		ADDI	\$10 -2	514		XORI	\$16 1
465		SUB	\$10 \$3	515	f_top_65_i:	BEQ	\$15 \$0
466		XORI	\$9 1		f_bot_66_i		
467	assert_true_44:	BRA	assert_46	516		ANDX	\$15 \$12 \$14
468	test_false_45:	BRA	test_43	517	cmp_bot_64_i:	BEQ	\$13 \$0
469	assert_46:	BNE	\$9 \$0		cmp_top_63_i		
	assert_true_44			518		XORI	\$14 1
470		ADD	\$10 \$3	519	cmp_top_63_i:	BEQ	\$13 \$0
471		ADDI	\$10 2		cmp_bot_64_i		
472		EXCH	\$11 \$10	520		EXCH	\$13 \$6
473		ADDI	\$10 -2	521	cmp_bot_62_i:	BNE	\$11 \$0
474		SUB	\$10 \$3		cmp_top_61_i		
475	cmp_top_53:	BEQ	\$11 \$0	522		XORI	\$12 1
	cmp_bot_54			523	cmp_top_61_i:	BNE	\$11 \$0
476		XORI	\$12 1		cmp_bot_62_i		
477	cmp_bot_54:	BEQ	\$11 \$0	524		ADD	\$10 \$3
	cmp_top_53			525		ADDI	\$10 3
478	f_top_55:	BEQ	\$12 \$0	526		EXCH	\$11 \$10
	f_bot_56			527		ADDI	\$10 -3
479		XORI	\$13 1	528		SUB	\$10 \$3
480	f_bot_56:	BEQ	\$12 \$0	529	test_57:	BEQ	\$9 \$0
	f_top_55				test_false_59		
481		XOR	\$9 \$13	530		XORI	\$9 1
482	f_bot_56_i:	BEQ	\$12 \$0	531		ADD	\$10 \$3
	f_top_55_i			532		ADDI	\$10 3
483		XORI	\$13 1	533		EXCH	\$11 \$10
484	f_top_55_i:	BEQ	\$12 \$0	534		ADDI	\$10 -3
	f_bot_56_i			535		SUB	\$10 \$3
485	cmp_bot_54_i:	BEQ	\$11 \$0	536		EXCH	\$12 \$6
	cmp_top_53_i			537	swap_67:	XOR	\$11 \$12
486		XORI	\$12 1	538		XOR	\$12 \$11
487	cmp_top_53_i:	BEQ	\$11 \$0	539		XOR	\$11 \$12
	cmp_bot_54_i			540		EXCH	\$12 \$6
488		ADD	\$10 \$3	541		ADD	\$10 \$3
489		ADDI	\$10 2	542		ADDI	\$10 3
490		EXCH	\$11 \$10	543		EXCH	\$11 \$10
491		ADDI	\$10 -2	544		ADDI	\$10 -3
492		SUB	\$10 \$3	545		SUB	\$10 \$3
493		XORI	\$8 1	546		XORI	\$9 1
494	assert_true_19:	BRA	assert_21	547	assert_true_58:	BRA	assert_60
495	test_false_20:	BRA	test_18	548	test_false_59:	BRA	test_57
496		ADD	\$10 \$3	549	assert_60:	BNE	\$9 \$0
497		ADDI	\$10 3		assert_true_58		
498		EXCH	\$11 \$10	550		ADD	\$10 \$3
499		ADDI	\$10 -3	551		ADDI	\$10 3
500		SUB	\$10 \$3	552		EXCH	\$11 \$10
501	cmp_top_61:	BNE	\$11 \$0	553		ADDI	\$10 -3
	cmp_bot_62			554		SUB	\$10 \$3
502		XORI	\$12 1	555	cmp_top_68:	BEQ	\$11 \$0
503	cmp_bot_62:	BNE	\$11 \$0		cmp_bot_69		
	cmp_top_61			556		XORI	\$12 1
504		EXCH	\$13 \$6	557	cmp_bot_69:	BEQ	\$11 \$0
505	cmp_top_63:	BEQ	\$13 \$0		cmp_top_68		
	cmp_bot_64			558		EXCH	\$13 \$6
506		XORI	\$14 1	559	cmp_top_70:	BNE	\$13 \$0
507	cmp_bot_64:	BEQ	\$13 \$0		cmp_bot_71		
	cmp_top_63			560		XORI	\$14 1
508		ANDX	\$15 \$12 \$14	561	cmp_bot_71:	BNE	\$13 \$0

	cmp_top_70			610		EXCH	\$11 \$10
562		ANDX	\$15 \$12 \$14	611		ADDI	\$10 -3
563	f_top_72:	BEQ	\$15 \$0	612		SUB	\$10 \$3
	f_bot_73			613		XOR	\$12 \$11
564		XORI	\$16 1	614	loadMetAdd_82:	EXCH	\$13 \$12
565	f_bot_73:	BEQ	\$15 \$0	615		ADDI	\$13 1
	f_top_72			616		EXCH	\$14 \$13
566		XOR	\$9 \$16	617		XOR	\$15 \$14
567	f_bot_73_i:	BEQ	\$15 \$0	618		EXCH	\$14 \$13
	f_top_72_i			619		ADDI	\$13 -1
568		XORI	\$16 1	620		EXCH	\$13 \$12
569	f_top_72_i:	BEQ	\$15 \$0	621		ADD	\$10 \$3
	f_bot_73_i			622		ADDI	\$10 3
570		ANDX	\$15 \$12 \$14	623		EXCH	\$11 \$10
571	cmp_bot_71_i:	BNE	\$13 \$0	624		ADDI	\$10 -3
	cmp_top_70_i			625		SUB	\$10 \$3
572		XORI	\$14 1	626		EXCH	\$3 \$1
573	cmp_top_70_i:	BNE	\$13 \$0	627		ADDI	\$1 -1
	cmp_bot_71_i			628		EXCH	\$6 \$1
574		EXCH	\$13 \$6	629		ADDI	\$1 -1
575	cmp_bot_69_i:	BEQ	\$11 \$0	630		EXCH	\$7 \$1
	cmp_top_68_i			631		ADDI	\$1 -1
576		XORI	\$12 1	632		EXCH	\$12 \$1
577	cmp_top_68_i:	BEQ	\$11 \$0	633		ADDI	\$1 -1
	cmp_bot_69_i			634		ADDI	\$15 -633
578		ADD	\$10 \$3	635	l_jump_83:	SWAPBR	\$15
579		ADDI	\$10 3	636		NEG	\$15
580		EXCH	\$11 \$10	637		ADDI	\$15 633
581		ADDI	\$10 -3	638		ADDI	\$1 1
582		SUB	\$10 \$3	639		EXCH	\$12 \$1
583		ADD	\$10 \$3	640		ADDI	\$1 1
584		ADDI	\$10 3	641		EXCH	\$7 \$1
585		EXCH	\$11 \$10	642		ADDI	\$1 1
586		ADDI	\$10 -3	643		EXCH	\$6 \$1
587		SUB	\$10 \$3	644		ADDI	\$1 1
588	cmp_top_78:	BEQ	\$11 \$0	645		EXCH	\$3 \$1
	cmp_bot_79			646		ADD	\$10 \$3
589		XORI	\$12 1	647		ADDI	\$10 3
590	cmp_bot_79:	BEQ	\$11 \$0	648		EXCH	\$11 \$10
	cmp_top_78			649		ADDI	\$10 -3
591	f_top_80:	BEQ	\$12 \$0	650		SUB	\$10 \$3
	f_bot_81			651		EXCH	\$13 \$12
592		XORI	\$13 1	652		ADDI	\$13 1
593	f_bot_81:	BEQ	\$12 \$0	653		EXCH	\$14 \$13
	f_top_80			654		XOR	\$15 \$14
594		XOR	\$9 \$13	655		EXCH	\$14 \$13
595	f_bot_81_i:	BEQ	\$12 \$0	656		ADDI	\$13 -1
	f_top_80_i			657	loadMetAdd_82_i:	EXCH	\$13 \$12
596		XORI	\$13 1	658		XOR	\$12 \$11
597	f_top_80_i:	BEQ	\$12 \$0	659		ADD	\$10 \$3
	f_bot_81_i			660		ADDI	\$10 3
598	cmp_bot_79_i:	BEQ	\$11 \$0	661		EXCH	\$11 \$10
	cmp_top_78_i			662		ADDI	\$10 -3
599		XORI	\$12 1	663		SUB	\$10 \$3
600	cmp_top_78_i:	BEQ	\$11 \$0	664		XORI	\$9 1
	cmp_bot_79_i			665	assert_true_75:	BRA	assert_77
601		ADD	\$10 \$3	666	test_false_76:	BRA	test_74
602		ADDI	\$10 3	667	assert_77:	BNE	\$9 \$0
603		EXCH	\$11 \$10		assert_true_75		
604		ADDI	\$10 -3	668		ADD	\$10 \$3
605		SUB	\$10 \$3	669		ADDI	\$10 3
606	test_74:	BEQ	\$9 \$0	670		EXCH	\$11 \$10
	test_false_76			671		ADDI	\$10 -3
607		XORI	\$9 1	672		SUB	\$10 \$3
608		ADD	\$10 \$3	673	cmp_top_84:	BEQ	\$11 \$0
609		ADDI	\$10 3		cmp_bot_85		

674		XORI	\$12 1	725		EXCH	\$6 \$1
675	cmp_bot_85:	BEQ	\$11 \$0	726		ADDI	\$1 -1
	cmp_top_84			727		EXCH	\$3 \$1
676	f_top_86:	BEQ	\$12 \$0	728		ADDI	\$1 -1
	f_bot_87			729	l_getSum_6:	SWAPBR	\$2
677		XORI	\$13 1	730		NEG	\$2
678	f_bot_87:	BEQ	\$12 \$0	731		ADDI	\$1 1
	f_top_86			732		EXCH	\$3 \$1
679		XOR	\$9 \$13	733		ADDI	\$1 1
680	f_bot_87_i:	BEQ	\$12 \$0	734		EXCH	\$6 \$1
	f_top_86_i			735		EXCH	\$2 \$1
681		XORI	\$13 1	736		ADDI	\$1 -1
682	f_top_86_i:	BEQ	\$12 \$0	737		EXCH	\$7 \$6
	f_bot_87_i			738		ADD	\$8 \$3
683	cmp_bot_85_i:	BEQ	\$11 \$0	739		ADDI	\$8 4
	cmp_top_84_i			740		EXCH	\$9 \$8
684		XORI	\$12 1	741		ADDI	\$8 -4
685	cmp_top_84_i:	BEQ	\$11 \$0	742		SUB	\$8 \$3
	cmp_bot_85_i			743		ADD	\$7 \$9
686		ADD	\$10 \$3	744		ADD	\$8 \$3
687		ADDI	\$10 3	745		ADDI	\$8 4
688		EXCH	\$11 \$10	746		EXCH	\$9 \$8
689		ADDI	\$10 -3	747		ADDI	\$8 -4
690		SUB	\$10 \$3	748		SUB	\$8 \$3
691	assert_21:	BNE	\$8 \$0	749		EXCH	\$7 \$6
	assert_true_19			750		ADD	\$8 \$3
692		EXCH	\$9 \$7	751		ADDI	\$8 2
693		ADD	\$10 \$3	752		EXCH	\$9 \$8
694		ADDI	\$10 4	753		ADDI	\$8 -2
695		EXCH	\$11 \$10	754		SUB	\$8 \$3
696		ADDI	\$10 -4	755	cmp_top_96:	BEQ	\$9 \$0
697		SUB	\$10 \$3		cmp_bot_97		
698		XOR	\$12 \$9	756		XORI	\$10 1
699		SUB	\$12 \$11	757	cmp_bot_97:	BEQ	\$9 \$0
700	cmp_top_88:	BGEZ	\$12 cmp_bot_89	758	cmp_top_96		
701		XORI	\$13 1	759	f_top_98:	BEQ	\$10 \$0
702	cmp_bot_89:	BGEZ	\$12 cmp_top_88		f_bot_99		
703	f_top_90:	BEQ	\$13 \$0	760	f_bot_99:	XORI	\$11 1
	f_bot_91				f_top_98	BEQ	\$10 \$0
704		XORI	\$14 1	761		XOR	\$7 \$11
705	f_bot_91:	BEQ	\$13 \$0	762	f_bot_99_i:	BEQ	\$10 \$0
	f_top_90				f_top_98_i		
706		XOR	\$8 \$14	763		XORI	\$11 1
707	f_bot_91_i:	BEQ	\$13 \$0	764	f_top_98_i:	BEQ	\$10 \$0
	f_top_90_i				f_bot_99_i		
708		XORI	\$14 1	765	cmp_bot_97_i:	BEQ	\$9 \$0
709	f_top_90_i:	BEQ	\$13 \$0		cmp_top_96_i		
	f_bot_91_i			766		XORI	\$10 1
710	cmp_bot_89_i:	BGEZ	\$12	767	cmp_top_96_i:	BEQ	\$9 \$0
	cmp_top_88_i				cmp_bot_97_i		
711		XORI	\$13 1	768		ADD	\$8 \$3
712	cmp_top_88_i:	BGEZ	\$12	769		ADDI	\$8 2
	cmp_bot_89_i			770		EXCH	\$9 \$8
713		ADD	\$12 \$11	771		ADDI	\$8 -2
714		XOR	\$12 \$9	772		SUB	\$8 \$3
715		ADD	\$10 \$3	773	test_92:	BEQ	\$7 \$0
716		ADDI	\$10 4		test_false_94		
717		EXCH	\$11 \$10	774		XORI	\$7 1
718		ADDI	\$10 -4	775		ADD	\$8 \$3
719		SUB	\$10 \$3	776		ADDI	\$8 2
720		EXCH	\$9 \$7	777		EXCH	\$9 \$8
721	l_insertNode_5_bot:	BRA		778		ADDI	\$8 -2
	l_insertNode_5_top			779		SUB	\$8 \$3
722	l_getSum_6_top:	BRA	l_getSum_6_bot	780		XOR	\$10 \$9
723		ADDI	\$1 1	781	loadMetAdd_100:	EXCH	\$11 \$10
724		EXCH	\$2 \$1				

782		ADDI	\$11 2	843	f_bot_105_i:	BEQ	\$10 \$0
783		EXCH	\$12 \$11		f_top_104_i		
784		XOR	\$13 \$12	844		XORI	\$11 1
785		EXCH	\$12 \$11	845	f_top_104_i:	BEQ	\$10 \$0
786		ADDI	\$11 -2		f_bot_105_i		
787		EXCH	\$11 \$10	846	cmp_bot_103_i:	BEQ	\$9 \$0
788		ADD	\$8 \$3		cmp_top_102_i		
789		ADDI	\$8 2	847		XORI	\$10 1
790		EXCH	\$9 \$8	848	cmp_top_102_i:	BEQ	\$9 \$0
791		ADDI	\$8 -2		cmp_bot_103_i		
792		SUB	\$8 \$3	849		ADD	\$8 \$3
793		EXCH	\$3 \$1	850		ADDI	\$8 2
794		ADDI	\$1 -1	851		EXCH	\$9 \$8
795		EXCH	\$6 \$1	852		ADDI	\$8 -2
796		ADDI	\$1 -1	853		SUB	\$8 \$3
797		EXCH	\$10 \$1	854		ADD	\$8 \$3
798		ADDI	\$1 -1	855		ADDI	\$8 3
799		ADDI	\$13 -798	856		EXCH	\$9 \$8
800	l_jump_101:	SWAPBR	\$13	857		ADDI	\$8 -3
801		NEG	\$13	858		SUB	\$8 \$3
802		ADDI	\$13 798	859	cmp_top_110:	BEQ	\$9 \$0
803		ADDI	\$1 1		cmp_bot_111		
804		EXCH	\$10 \$1	860		XORI	\$10 1
805		ADDI	\$1 1	861	cmp_bot_111:	BEQ	\$9 \$0
806		EXCH	\$6 \$1		cmp_top_110		
807		ADDI	\$1 1	862	f_top_112:	BEQ	\$10 \$0
808		EXCH	\$3 \$1		f_bot_113		
809		ADD	\$8 \$3	863		XORI	\$11 1
810		ADDI	\$8 2	864	f_bot_113:	BEQ	\$10 \$0
811		EXCH	\$9 \$8		f_top_112		
812		ADDI	\$8 -2	865		XOR	\$7 \$11
813		SUB	\$8 \$3	866	f_bot_113_i:	BEQ	\$10 \$0
814		EXCH	\$11 \$10		f_top_112_i		
815		ADDI	\$11 2	867		XORI	\$11 1
816		EXCH	\$12 \$11	868	f_top_112_i:	BEQ	\$10 \$0
817		XOR	\$13 \$12		f_bot_113_i		
818		EXCH	\$12 \$11	869	cmp_bot_111_i:	BEQ	\$9 \$0
819		ADDI	\$11 -2		cmp_top_110_i		
820	loadMetAdd_100_i:	EXCH	\$11 \$10	870		XORI	\$10 1
821		XOR	\$10 \$9	871	cmp_top_110_i:	BEQ	\$9 \$0
822		ADD	\$8 \$3		cmp_bot_111_i		
823		ADDI	\$8 2	872		ADD	\$8 \$3
824		EXCH	\$9 \$8	873		ADDI	\$8 3
825		ADDI	\$8 -2	874		EXCH	\$9 \$8
826		SUB	\$8 \$3	875		ADDI	\$8 -3
827		XORI	\$7 1	876		SUB	\$8 \$3
828	assert_true_93:	BRA	assert_95	877	test_106:	BEQ	\$7 \$0
829	test_false_94:	BRA	test_92		test_false_108		
830	assert_95:	BNE	\$7 \$0	878		XORI	\$7 1
	assert_true_93			879		ADD	\$8 \$3
831		ADD	\$8 \$3	880		ADDI	\$8 3
832		ADDI	\$8 2	881		EXCH	\$9 \$8
833		EXCH	\$9 \$8	882		ADDI	\$8 -3
834		ADDI	\$8 -2	883		SUB	\$8 \$3
835		SUB	\$8 \$3	884		XOR	\$10 \$9
836	cmp_top_102:	BEQ	\$9 \$0	885	loadMetAdd_114:	EXCH	\$11 \$10
	cmp_bot_103			886		ADDI	\$11 2
837		XORI	\$10 1	887		EXCH	\$12 \$11
838	cmp_bot_103:	BEQ	\$9 \$0	888		XOR	\$13 \$12
	cmp_top_102			889		EXCH	\$12 \$11
839	f_top_104:	BEQ	\$10 \$0	890		ADDI	\$11 -2
	f_bot_105			891		EXCH	\$11 \$10
840		XORI	\$11 1	892		ADD	\$8 \$3
841	f_bot_105:	BEQ	\$10 \$0	893		ADDI	\$8 3
	f_top_104			894		EXCH	\$9 \$8
842		XOR	\$7 \$11	895		ADDI	\$8 -3

896		SUB	\$8 \$3	953		ADD	\$8 \$3
897		EXCH	\$3 \$1	954		ADDI	\$8 3
898		ADDI	\$1 -1	955		EXCH	\$9 \$8
899		EXCH	\$6 \$1	956		ADDI	\$8 -3
900		ADDI	\$1 -1	957		SUB	\$8 \$3
901		EXCH	\$10 \$1	958	l_getSum_6_bot:	BRA	l_getSum_6_top
902		ADDI	\$1 -1	959	l_mirror_7_top:	BRA	l_mirror_7_bot
903		ADDI	\$13 -902	960		ADDI	\$1 1
904	l_jmp_115:	SWAPBR	\$13	961		EXCH	\$2 \$1
905		NEG	\$13	962		EXCH	\$3 \$1
906		ADDI	\$13 902	963		ADDI	\$1 -1
907		ADDI	\$1 1	964	l_mirror_7:	SWAPBR	\$2
908		EXCH	\$10 \$1	965		NEG	\$2
909		ADDI	\$1 1	966		ADDI	\$1 1
910		EXCH	\$6 \$1	967		EXCH	\$3 \$1
911		ADDI	\$1 1	968		EXCH	\$2 \$1
912		EXCH	\$3 \$1	969		ADDI	\$1 -1
913		ADD	\$8 \$3	970		ADD	\$6 \$3
914		ADDI	\$8 3	971		ADDI	\$6 2
915		EXCH	\$9 \$8	972		EXCH	\$7 \$6
916		ADDI	\$8 -3	973		ADDI	\$6 -2
917		SUB	\$8 \$3	974		SUB	\$6 \$3
918		EXCH	\$11 \$10	975		ADD	\$8 \$3
919		ADDI	\$11 2	976		ADDI	\$8 3
920		EXCH	\$12 \$11	977		EXCH	\$9 \$8
921		XOR	\$13 \$12	978		ADDI	\$8 -3
922		EXCH	\$12 \$11	979		SUB	\$8 \$3
923		ADDI	\$11 -2	980	swap_120:	XOR	\$7 \$9
924	loadMetAdd_114_i:	EXCH	\$11 \$10	981		XOR	\$9 \$7
925		XOR	\$10 \$9	982		XOR	\$7 \$9
926		ADD	\$8 \$3	983		ADD	\$8 \$3
927		ADDI	\$8 3	984		ADDI	\$8 3
928		EXCH	\$9 \$8	985		EXCH	\$9 \$8
929		ADDI	\$8 -3	986		ADDI	\$8 -3
930		SUB	\$8 \$3	987		SUB	\$8 \$3
931		XORI	\$7 1	988		ADD	\$6 \$3
932	assert_true_107:	BRA	assert_109	989		ADDI	\$6 2
933	test_false_108:	BRA	test_106	990		EXCH	\$7 \$6
934	assert_109:	BNE	\$7 \$0	991		ADDI	\$6 -2
	assert_true_107			992		SUB	\$6 \$3
935		ADD	\$8 \$3	993		ADD	\$7 \$3
936		ADDI	\$8 3	994		ADDI	\$7 2
937		EXCH	\$9 \$8	995		EXCH	\$8 \$7
938		ADDI	\$8 -3	996		ADDI	\$7 -2
939		SUB	\$8 \$3	997		SUB	\$7 \$3
940	cmp_top_116:	BEQ	\$9 \$0	998	cmp_top_125:	BNE	\$8 \$0
	cmp_bot_117				cmp_bot_126		
941		XORI	\$10 1	999		XORI	\$9 1
942	cmp_bot_117:	BEQ	\$9 \$0	1000	cmp_bot_126:	BNE	\$8 \$0
	cmp_top_116				cmp_top_125		
943	f_top_118:	BEQ	\$10 \$0	1001	f_top_127:	BEQ	\$9 \$0
	f_bot_119				f_bot_128		
944		XORI	\$11 1	1002		XORI	\$10 1
945	f_bot_119:	BEQ	\$10 \$0	1003	f_bot_128:	BEQ	\$9 \$0
	f_top_118				f_top_127		
946		XOR	\$7 \$11	1004		XOR	\$6 \$10
947	f_bot_119_i:	BEQ	\$10 \$0	1005	f_bot_128_i:	BEQ	\$9 \$0
	f_top_118_i				f_top_127_i		
948		XORI	\$11 1	1006		XORI	\$10 1
949	f_top_118_i:	BEQ	\$10 \$0	1007	f_top_127_i:	BEQ	\$9 \$0
	f_bot_119_i				f_bot_128_i		
950	cmp_bot_117_i:	BEQ	\$9 \$0	1008	cmp_bot_126_i:	BNE	\$8 \$0
	cmp_top_116_i				cmp_top_125_i		
951		XORI	\$10 1	1009		XORI	\$9 1
952	cmp_top_116_i:	BEQ	\$9 \$0	1010	cmp_top_125_i:	BNE	\$8 \$0
	cmp_bot_117_i				cmp_bot_126_i		

1011		ADD	\$7 \$3	1075	cmp_top_131:	BNE	\$8 \$0
1012		ADDI	\$7 2		cmp_bot_132		
1013		EXCH	\$8 \$7	1076		XORI	\$9 1
1014		ADDI	\$7 -2	1077	cmp_bot_132:	BNE	\$8 \$0
1015		SUB	\$7 \$3		cmp_top_131		
1016	test_121:	BEQ	\$6 \$0	1078	f_top_133:	BEQ	\$9 \$0
	test_false_123				f_bot_134		
1017		XORI	\$6 1	1079		XORI	\$10 1
1018		XORI	\$6 1	1080	f_bot_134:	BEQ	\$9 \$0
1019	assert_true_122:	BRA	assert_124		f_top_133		
1020	test_false_123:	BRA	test_121	1081		XOR	\$6 \$10
1021		ADD	\$7 \$3	1082	f_bot_134_i:	BEQ	\$9 \$0
1022		ADDI	\$7 2		f_top_133_i		
1023		EXCH	\$8 \$7	1083		XORI	\$10 1
1024		ADDI	\$7 -2	1084	f_top_133_i:	BEQ	\$9 \$0
1025		SUB	\$7 \$3		f_bot_134_i		
1026		XOR	\$9 \$8	1085	cmp_bot_132_i:	BNE	\$8 \$0
1027	loadMetAdd_129:	EXCH	\$10 \$9		cmp_top_131_i		
1028		ADDI	\$10 3	1086		XORI	\$9 1
1029		EXCH	\$11 \$10	1087	cmp_top_131_i:	BNE	\$8 \$0
1030		XOR	\$12 \$11		cmp_bot_132_i		
1031		EXCH	\$11 \$10	1088		ADD	\$7 \$3
1032		ADDI	\$10 -3	1089		ADDI	\$7 2
1033		EXCH	\$10 \$9	1090		EXCH	\$8 \$7
1034		ADD	\$7 \$3	1091		ADDI	\$7 -2
1035		ADDI	\$7 2	1092		SUB	\$7 \$3
1036		EXCH	\$8 \$7	1093		ADD	\$7 \$3
1037		ADDI	\$7 -2	1094		ADDI	\$7 3
1038		SUB	\$7 \$3	1095		EXCH	\$8 \$7
1039		EXCH	\$3 \$1	1096		ADDI	\$7 -3
1040		ADDI	\$1 -1	1097		SUB	\$7 \$3
1041		EXCH	\$9 \$1	1098	cmp_top_139:	BNE	\$8 \$0
1042		ADDI	\$1 -1		cmp_bot_140		
1043		ADDI	\$12 -1042	1099		XORI	\$9 1
1044	l_jump_130:	SWAPBR	\$12	1100	cmp_bot_140:	BNE	\$8 \$0
1045		NEG	\$12		cmp_top_139		
1046		ADDI	\$12 1042	1101	f_top_141:	BEQ	\$9 \$0
1047		ADDI	\$1 1		f_bot_142		
1048		EXCH	\$9 \$1	1102		XORI	\$10 1
1049		ADDI	\$1 1	1103	f_bot_142:	BEQ	\$9 \$0
1050		EXCH	\$3 \$1		f_top_141		
1051		ADD	\$7 \$3	1104		XOR	\$6 \$10
1052		ADDI	\$7 2	1105	f_bot_142_i:	BEQ	\$9 \$0
1053		EXCH	\$8 \$7		f_top_141_i		
1054		ADDI	\$7 -2	1106		XORI	\$10 1
1055		SUB	\$7 \$3	1107	f_top_141_i:	BEQ	\$9 \$0
1056		EXCH	\$10 \$9		f_bot_142_i		
1057		ADDI	\$10 3	1108	cmp_bot_140_i:	BNE	\$8 \$0
1058		EXCH	\$11 \$10		cmp_top_139_i		
1059		XOR	\$12 \$11	1109		XORI	\$9 1
1060		EXCH	\$11 \$10	1110	cmp_top_139_i:	BNE	\$8 \$0
1061		ADDI	\$10 -3		cmp_bot_140_i		
1062	loadMetAdd_129_i:	EXCH	\$10 \$9	1111		ADD	\$7 \$3
1063		XOR	\$9 \$8	1112		ADDI	\$7 3
1064		ADD	\$7 \$3	1113		EXCH	\$8 \$7
1065		ADDI	\$7 2	1114		ADDI	\$7 -3
1066		EXCH	\$8 \$7	1115		SUB	\$7 \$3
1067		ADDI	\$7 -2	1116	test_135:	BEQ	\$6 \$0
1068		SUB	\$7 \$3		test_false_137		
1069	assert_124:	BNE	\$6 \$0	1117		XORI	\$6 1
	assert_true_122			1118		XORI	\$6 1
1070		ADD	\$7 \$3	1119	assert_true_136:	BRA	assert_138
1071		ADDI	\$7 2	1120	test_false_137:	BRA	test_135
1072		EXCH	\$8 \$7	1121		ADD	\$7 \$3
1073		ADDI	\$7 -2	1122		ADDI	\$7 3
1074		SUB	\$7 \$3	1123		EXCH	\$8 \$7

1124		ADDI	\$7 -3	1184	f_top_147_i:	BEQ	\$9 \$0
1125		SUB	\$7 \$3		f_bot_148_i		
1126		XOR	\$9 \$8	1185	cmp_bot_146_i:	BNE	\$8 \$0
1127	loadMetAdd_143:	EXCH	\$10 \$9		cmp_top_145_i		
1128		ADDI	\$10 3	1186		XORI	\$9 1
1129		EXCH	\$11 \$10	1187	cmp_top_145_i:	BNE	\$8 \$0
1130		XOR	\$12 \$11		cmp_bot_146_i		
1131		EXCH	\$11 \$10	1188		ADD	\$7 \$3
1132		ADDI	\$10 -3	1189		ADDI	\$7 3
1133		EXCH	\$10 \$9	1190		EXCH	\$8 \$7
1134		ADD	\$7 \$3	1191		ADDI	\$7 -3
1135		ADDI	\$7 3	1192		SUB	\$7 \$3
1136		EXCH	\$8 \$7	1193	l_mirror_7_bot:	BRA	l_mirror_7_top
1137		ADDI	\$7 -3	1194	l_insertNode_1_top:	BRA	
1138		SUB	\$7 \$3		l_insertNode_1_bot		
1139		EXCH	\$3 \$1	1195		ADDI	\$1 1
1140		ADDI	\$1 -1	1196		EXCH	\$2 \$1
1141		EXCH	\$9 \$1	1197		EXCH	\$6 \$1
1142		ADDI	\$1 -1	1198		ADDI	\$1 -1
1143		ADDI	\$12 -1142	1199		EXCH	\$7 \$1
1144	l_jump_144:	SWAPBR	\$12	1200		ADDI	\$1 -1
1145		NEG	\$12	1201		EXCH	\$3 \$1
1146		ADDI	\$12 1142	1202		ADDI	\$1 -1
1147		ADDI	\$1 1	1203	l_insertNode_1:	SWAPBR	\$2
1148		EXCH	\$9 \$1	1204		NEG	\$2
1149		ADDI	\$1 1	1205		ADDI	\$1 1
1150		EXCH	\$3 \$1	1206		EXCH	\$3 \$1
1151		ADD	\$7 \$3	1207		ADDI	\$1 1
1152		ADDI	\$7 3	1208		EXCH	\$7 \$1
1153		EXCH	\$8 \$7	1209		ADDI	\$1 1
1154		ADDI	\$7 -3	1210		EXCH	\$6 \$1
1155		SUB	\$7 \$3	1211		EXCH	\$2 \$1
1156		EXCH	\$10 \$9	1212		ADDI	\$1 -1
1157		ADDI	\$10 3	1213		ADD	\$9 \$3
1158		EXCH	\$11 \$10	1214		ADDI	\$9 2
1159		XOR	\$12 \$11	1215		EXCH	\$10 \$9
1160		EXCH	\$11 \$10	1216		ADDI	\$9 -2
1161		ADDI	\$10 -3	1217		SUB	\$9 \$3
1162	loadMetAdd_143_i:	EXCH	\$10 \$9	1218	cmp_top_153:	BNE	\$10 \$0
1163		XOR	\$9 \$8		cmp_bot_154		
1164		ADD	\$7 \$3	1219		XORI	\$11 1
1165		ADDI	\$7 3	1220	cmp_bot_154:	BNE	\$10 \$0
1166		EXCH	\$8 \$7		cmp_top_153		
1167		ADDI	\$7 -3	1221		EXCH	\$12 \$6
1168		SUB	\$7 \$3	1222	cmp_top_155:	BEQ	\$12 \$0
1169	assert_138:	BNE	\$6 \$0		cmp_bot_156		
	assert_true_136			1223		XORI	\$13 1
1170		ADD	\$7 \$3	1224	cmp_bot_156:	BEQ	\$12 \$0
1171		ADDI	\$7 3		cmp_top_155		
1172		EXCH	\$8 \$7	1225		ANDX	\$14 \$11 \$13
1173		ADDI	\$7 -3	1226	f_top_157:	BEQ	\$14 \$0
1174		SUB	\$7 \$3		f_bot_158		
1175	cmp_top_145:	BNE	\$8 \$0	1227		XORI	\$15 1
	cmp_bot_146			1228	f_bot_158:	BEQ	\$14 \$0
1176		XORI	\$9 1		f_top_157		
1177	cmp_bot_146:	BNE	\$8 \$0	1229		XOR	\$8 \$15
	cmp_top_145			1230	f_bot_158_i:	BEQ	\$14 \$0
1178	f_top_147:	BEQ	\$9 \$0		f_top_157_i		
	f_bot_148			1231		XORI	\$15 1
1179		XORI	\$10 1	1232	f_top_157_i:	BEQ	\$14 \$0
1180	f_bot_148:	BEQ	\$9 \$0		f_bot_158_i		
	f_top_147			1233		ANDX	\$14 \$11 \$13
1181		XOR	\$6 \$10	1234	cmp_bot_156_i:	BEQ	\$12 \$0
1182	f_bot_148_i:	BEQ	\$9 \$0		cmp_top_155_i		
	f_top_147_i			1235		XORI	\$13 1
1183		XORI	\$10 1	1236	cmp_top_155_i:	BEQ	\$12 \$0

1237	cmp_bot_156_i			1289		XORI	\$13 1
1238	cmp_bot_154_i:	EXCH	\$12 \$6	1290	cmp_top_162_i:	BNE	\$12 \$0
	cmp_top_153_i	BNE	\$10 \$0		cmp_bot_163_i		
1239		XORI	\$11 1	1291		EXCH	\$12 \$6
1240	cmp_top_153_i:	BNE	\$10 \$0	1292	cmp_bot_161_i:	BEQ	\$10 \$0
	cmp_bot_154_i				cmp_top_160_i		
1241		ADD	\$9 \$3	1293		XORI	\$11 1
1242		ADDI	\$9 2	1294	cmp_top_160_i:	BEQ	\$10 \$0
1243		EXCH	\$10 \$9		cmp_bot_161_i		
1244		ADDI	\$9 -2	1295		ADD	\$9 \$3
1245		SUB	\$9 \$3	1296		ADDI	\$9 2
1246	test_149:	BEQ	\$8 \$0	1297		EXCH	\$10 \$9
	test_false_151			1298		ADDI	\$9 -2
1247		XORI	\$8 1	1299		SUB	\$9 \$3
1248		ADD	\$9 \$3	1300		ADD	\$9 \$3
1249		ADDI	\$9 2	1301		ADDI	\$9 2
1250		EXCH	\$10 \$9	1302		EXCH	\$10 \$9
1251		ADDI	\$9 -2	1303		ADDI	\$9 -2
1252		SUB	\$9 \$3	1304		SUB	\$9 \$3
1253		EXCH	\$11 \$6	1305	cmp_top_170:	BEQ	\$10 \$0
1254	swap_159:	XOR	\$10 \$11		cmp_bot_171		
1255		XOR	\$11 \$10	1306		XORI	\$11 1
1256		XOR	\$10 \$11	1307	cmp_bot_171:	BEQ	\$10 \$0
1257		EXCH	\$11 \$6		cmp_top_170		
1258		ADD	\$9 \$3	1308	f_top_172:	BEQ	\$11 \$0
1259		ADDI	\$9 2		f_bot_173		
1260		EXCH	\$10 \$9	1309		XORI	\$12 1
1261		ADDI	\$9 -2	1310	f_bot_173:	BEQ	\$11 \$0
1262		SUB	\$9 \$3		f_top_172		
1263		XORI	\$8 1	1311		XOR	\$8 \$12
1264	assert_true_150:	BRA	assert_152	1312	f_bot_173_i:	BEQ	\$11 \$0
1265	test_false_151:	BRA	test_149		f_top_172_i		
1266	assert_152:	BNE	\$8 \$0	1313		XORI	\$12 1
	assert_true_150			1314	f_top_172_i:	BEQ	\$11 \$0
1267		ADD	\$9 \$3		f_bot_173_i		
1268		ADDI	\$9 2	1315	cmp_bot_171_i:	BEQ	\$10 \$0
1269		EXCH	\$10 \$9		cmp_top_170_i		
1270		ADDI	\$9 -2	1316		XORI	\$11 1
1271		SUB	\$9 \$3	1317	cmp_top_170_i:	BEQ	\$10 \$0
1272	cmp_top_160:	BEQ	\$10 \$0		cmp_bot_171_i		
	cmp_bot_161			1318		ADD	\$9 \$3
1273		XORI	\$11 1	1319		ADDI	\$9 2
1274	cmp_bot_161:	BEQ	\$10 \$0	1320		EXCH	\$10 \$9
	cmp_top_160			1321		ADDI	\$9 -2
1275		EXCH	\$12 \$6	1322		SUB	\$9 \$3
1276	cmp_top_162:	BNE	\$12 \$0	1323	test_166:	BEQ	\$8 \$0
	cmp_bot_163				test_false_168		
1277		XORI	\$13 1	1324		XORI	\$8 1
1278	cmp_bot_163:	BNE	\$12 \$0	1325		ADD	\$9 \$3
	cmp_top_162			1326		ADDI	\$9 2
1279		ANDX	\$14 \$11 \$13	1327		EXCH	\$10 \$9
1280	f_top_164:	BEQ	\$14 \$0	1328		ADDI	\$9 -2
	f_bot_165			1329		SUB	\$9 \$3
1281		XORI	\$15 1	1330		XOR	\$11 \$10
1282	f_bot_165:	BEQ	\$14 \$0	1331	loadMetAdd_174:	EXCH	\$12 \$11
	f_top_164			1332		ADDI	\$12 1
1283		XOR	\$8 \$15	1333		EXCH	\$13 \$12
1284	f_bot_165_i:	BEQ	\$14 \$0	1334		XOR	\$14 \$13
	f_top_164_i			1335		EXCH	\$13 \$12
1285		XORI	\$15 1	1336		ADDI	\$12 -1
1286	f_top_164_i:	BEQ	\$14 \$0	1337		EXCH	\$12 \$11
	f_bot_165_i			1338		ADD	\$9 \$3
1287		ANDX	\$14 \$11 \$13	1339		ADDI	\$9 2
1288	cmp_bot_163_i:	BNE	\$12 \$0	1340		EXCH	\$10 \$9
	cmp_top_162_i			1341		ADDI	\$9 -2
				1342		SUB	\$9 \$3

1343		EXCH	\$3 \$1	1401		XORI	\$11 1
1344		ADDI	\$1 -1	1402	cmp_top_176_i:	BEQ	\$10 \$0
1345		EXCH	\$6 \$1		cmp_bot_177_i		
1346		ADDI	\$1 -1	1403		ADD	\$9 \$3
1347		EXCH	\$7 \$1	1404		ADDI	\$9 2
1348		ADDI	\$1 -1	1405		EXCH	\$10 \$9
1349		EXCH	\$11 \$1	1406		ADDI	\$9 -2
1350		ADDI	\$1 -1	1407		SUB	\$9 \$3
1351		ADDI	\$14 -1350	1408	l_insertNode_1_bot:	BRA	
1352	l_jump_175:	SWAPBR	\$14		l_insertNode_1_top		
1353		NEG	\$14	1409	l_sum_2_top:	BRA	l_sum_2_bot
1354		ADDI	\$14 1350	1410		ADDI	\$1 1
1355		ADDI	\$1 1	1411		EXCH	\$2 \$1
1356		EXCH	\$11 \$1	1412		EXCH	\$6 \$1
1357		ADDI	\$1 1	1413		ADDI	\$1 -1
1358		EXCH	\$7 \$1	1414		EXCH	\$3 \$1
1359		ADDI	\$1 1	1415		ADDI	\$1 -1
1360		EXCH	\$6 \$1	1416	l_sum_2:	SWAPBR	\$2
1361		ADDI	\$1 1	1417		NEG	\$2
1362		EXCH	\$3 \$1	1418		ADDI	\$1 1
1363		ADD	\$9 \$3	1419		EXCH	\$3 \$1
1364		ADDI	\$9 2	1420		ADDI	\$1 1
1365		EXCH	\$10 \$9	1421		EXCH	\$6 \$1
1366		ADDI	\$9 -2	1422		EXCH	\$2 \$1
1367		SUB	\$9 \$3	1423		ADDI	\$1 -1
1368		EXCH	\$12 \$11	1424		ADD	\$8 \$3
1369		ADDI	\$12 1	1425		ADDI	\$8 2
1370		EXCH	\$13 \$12	1426		EXCH	\$9 \$8
1371		XOR	\$14 \$13	1427		ADDI	\$8 -2
1372		EXCH	\$13 \$12	1428		SUB	\$8 \$3
1373		ADDI	\$12 -1	1429	cmp_top_184:	BEQ	\$9 \$0
1374	loadMetAdd_174_i:	EXCH	\$12 \$11		cmp_bot_185		
1375		XOR	\$11 \$10	1430		XORI	\$10 1
1376		ADD	\$9 \$3	1431	cmp_bot_185:	BEQ	\$9 \$0
1377		ADDI	\$9 2		cmp_top_184		
1378		EXCH	\$10 \$9	1432	f_top_186:	BEQ	\$10 \$0
1379		ADDI	\$9 -2		f_bot_187		
1380		SUB	\$9 \$3	1433		XORI	\$11 1
1381		XORI	\$8 1	1434	f_bot_187:	BEQ	\$10 \$0
1382	assert_true_167:	BRA	assert_169		f_top_186		
1383	test_false_168:	BRA	test_166	1435		XOR	\$7 \$11
1384	assert_169:	BNE	\$8 \$0	1436	f_bot_187_i:	BEQ	\$10 \$0
	assert_true_167				f_top_186_i		
1385		ADD	\$9 \$3	1437		XORI	\$11 1
1386		ADDI	\$9 2	1438	f_top_186_i:	BEQ	\$10 \$0
1387		EXCH	\$10 \$9		f_bot_187_i		
1388		ADDI	\$9 -2	1439	cmp_bot_185_i:	BEQ	\$9 \$0
1389		SUB	\$9 \$3		cmp_top_184_i		
1390	cmp_top_176:	BEQ	\$10 \$0	1440		XORI	\$10 1
	cmp_bot_177			1441	cmp_top_184_i:	BEQ	\$9 \$0
1391		XORI	\$11 1		cmp_bot_185_i		
1392	cmp_bot_177:	BEQ	\$10 \$0	1442		ADD	\$8 \$3
	cmp_top_176			1443		ADDI	\$8 2
1393	f_top_178:	BEQ	\$11 \$0	1444		EXCH	\$9 \$8
	f_bot_179			1445		ADDI	\$8 -2
1394		XORI	\$12 1	1446		SUB	\$8 \$3
1395	f_bot_179:	BEQ	\$11 \$0	1447	test_180:	BEQ	\$7 \$0
	f_top_178				test_false_182		
1396		XOR	\$8 \$12	1448		XORI	\$7 1
1397	f_bot_179_i:	BEQ	\$11 \$0	1449		ADD	\$8 \$3
	f_top_178_i			1450		ADDI	\$8 2
1398		XORI	\$12 1	1451		EXCH	\$9 \$8
1399	f_top_178_i:	BEQ	\$11 \$0	1452		ADDI	\$8 -2
	f_bot_179_i			1453		SUB	\$8 \$3
1400	cmp_bot_177_i:	BEQ	\$10 \$0	1454		XOR	\$10 \$9
	cmp_top_176_i			1455	loadMetAdd_188:	EXCH	\$11 \$10

1456		ADDI	\$11 2	1517	f_bot_193_i:	BEQ	\$10 \$0
1457		EXCH	\$12 \$11		f_top_192_i		
1458		XOR	\$13 \$12	1518		XORI	\$11 1
1459		EXCH	\$12 \$11	1519	f_top_192_i:	BEQ	\$10 \$0
1460		ADDI	\$11 -2		f_bot_193_i		
1461		EXCH	\$11 \$10	1520	cmp_bot_191_i:	BEQ	\$9 \$0
1462		ADD	\$8 \$3		cmp_top_190_i		
1463		ADDI	\$8 2	1521		XORI	\$10 1
1464		EXCH	\$9 \$8	1522	cmp_top_190_i:	BEQ	\$9 \$0
1465		ADDI	\$8 -2		cmp_bot_191_i		
1466		SUB	\$8 \$3	1523		ADD	\$8 \$3
1467		EXCH	\$3 \$1	1524		ADDI	\$8 2
1468		ADDI	\$1 -1	1525		EXCH	\$9 \$8
1469		EXCH	\$6 \$1	1526		ADDI	\$8 -2
1470		ADDI	\$1 -1	1527		SUB	\$8 \$3
1471		EXCH	\$10 \$1	1528	l_sum_2_bot:	BRA	l_sum_2_top
1472		ADDI	\$1 -1	1529	l_mirror_3_top:	BRA	l_mirror_3_bot
1473		ADDI	\$13 -1472	1530		ADDI	\$1 1
1474	l_jump_189:	SWAPBR	\$13	1531		EXCH	\$2 \$1
1475		NEG	\$13	1532		EXCH	\$3 \$1
1476		ADDI	\$13 1472	1533		ADDI	\$1 -1
1477		ADDI	\$1 1	1534	l_mirror_3:	SWAPBR	\$2
1478		EXCH	\$10 \$1	1535		NEG	\$2
1479		ADDI	\$1 1	1536		ADDI	\$1 1
1480		EXCH	\$6 \$1	1537		EXCH	\$3 \$1
1481		ADDI	\$1 1	1538		EXCH	\$2 \$1
1482		EXCH	\$3 \$1	1539		ADDI	\$1 -1
1483		ADD	\$8 \$3	1540		ADD	\$7 \$3
1484		ADDI	\$8 2	1541		ADDI	\$7 2
1485		EXCH	\$9 \$8	1542		EXCH	\$8 \$7
1486		ADDI	\$8 -2	1543		ADDI	\$7 -2
1487		SUB	\$8 \$3	1544		SUB	\$7 \$3
1488		EXCH	\$11 \$10	1545	cmp_top_198:	BEQ	\$8 \$0
1489		ADDI	\$11 2		cmp_bot_199		
1490		EXCH	\$12 \$11	1546		XORI	\$9 1
1491		XOR	\$13 \$12	1547	cmp_bot_199:	BEQ	\$8 \$0
1492		EXCH	\$12 \$11		cmp_top_198		
1493		ADDI	\$11 -2	1548	f_top_200:	BEQ	\$9 \$0
1494	loadMetAdd_188_i:	EXCH	\$11 \$10		f_bot_201		
1495		XOR	\$10 \$9	1549		XORI	\$10 1
1496		ADD	\$8 \$3	1550	f_bot_201:	BEQ	\$9 \$0
1497		ADDI	\$8 2		f_top_200		
1498		EXCH	\$9 \$8	1551		XOR	\$6 \$10
1499		ADDI	\$8 -2	1552	f_bot_201_i:	BEQ	\$9 \$0
1500		SUB	\$8 \$3		f_top_200_i		
1501		XORI	\$7 1	1553		XORI	\$10 1
1502	assert_true_181:	BRA	assert_183	1554	f_top_200_i:	BEQ	\$9 \$0
1503	test_false_182:	BRA	test_180		f_bot_201_i		
1504	assert_183:	BNE	\$7 \$0	1555	cmp_bot_199_i:	BEQ	\$8 \$0
	assert_true_181				cmp_top_198_i		
1505		ADD	\$8 \$3	1556		XORI	\$9 1
1506		ADDI	\$8 2	1557	cmp_top_198_i:	BEQ	\$8 \$0
1507		EXCH	\$9 \$8		cmp_bot_199_i		
1508		ADDI	\$8 -2	1558		ADD	\$7 \$3
1509		SUB	\$8 \$3	1559		ADDI	\$7 2
1510	cmp_top_190:	BEQ	\$9 \$0	1560		EXCH	\$8 \$7
	cmp_bot_191			1561		ADDI	\$7 -2
1511		XORI	\$10 1	1562		SUB	\$7 \$3
1512	cmp_bot_191:	BEQ	\$9 \$0	1563	test_194:	BEQ	\$6 \$0
	cmp_top_190				test_false_196		
1513	f_top_192:	BEQ	\$10 \$0	1564		XORI	\$6 1
	f_bot_193			1565		ADD	\$7 \$3
1514		XORI	\$11 1	1566		ADDI	\$7 2
1515	f_bot_193:	BEQ	\$10 \$0	1567		EXCH	\$8 \$7
	f_top_192			1568		ADDI	\$7 -2
1516		XOR	\$7 \$11	1569		SUB	\$7 \$3

1570		XOR	\$9 \$8	1630		XORI	\$10 1
1571	loadMetAdd_202:	EXCH	\$10 \$9	1631	f_top_206_i:	BEQ	\$9 \$0
1572		ADDI	\$10 3		f_bot_207_i		
1573		EXCH	\$11 \$10	1632	cmp_bot_205_i:	BEQ	\$8 \$0
1574		XOR	\$12 \$11		cmp_top_204_i		
1575		EXCH	\$11 \$10	1633		XORI	\$9 1
1576		ADDI	\$10 -3	1634	cmp_top_204_i:	BEQ	\$8 \$0
1577		EXCH	\$10 \$9		cmp_bot_205_i		
1578		ADD	\$7 \$3	1635		ADD	\$7 \$3
1579		ADDI	\$7 2	1636		ADDI	\$7 2
1580		EXCH	\$8 \$7	1637		EXCH	\$8 \$7
1581		ADDI	\$7 -2	1638		ADDI	\$7 -2
1582		SUB	\$7 \$3	1639		SUB	\$7 \$3
1583		EXCH	\$3 \$1	1640	l_mirror_3_bot:	BRA	l_mirror_3_top
1584		ADDI	\$1 -1	1641	l_main_0_top:	BRA	l_main_0_bot
1585		EXCH	\$9 \$1	1642		ADDI	\$1 1
1586		ADDI	\$1 -1	1643		EXCH	\$2 \$1
1587		ADDI	\$12 -1586	1644		EXCH	\$3 \$1
1588	l_jmp_203:	SWAPBR	\$12	1645		ADDI	\$1 -1
1589		NEG	\$12	1646	l_main_0:	SWAPBR	\$2
1590		ADDI	\$12 1586	1647		NEG	\$2
1591		ADDI	\$1 1	1648		ADDI	\$1 1
1592		EXCH	\$9 \$1	1649		EXCH	\$3 \$1
1593		ADDI	\$1 1	1650		EXCH	\$2 \$1
1594		EXCH	\$3 \$1	1651		ADDI	\$1 -1
1595		ADD	\$7 \$3	1652		EXCH	\$3 \$1
1596		ADDI	\$7 2	1653		ADDI	\$1 -1
1597		EXCH	\$8 \$7	1654	obj_con_208:	ADDI	\$8 4
1598		ADDI	\$7 -2	1655		EXCH	\$8 \$1
1599		SUB	\$7 \$3	1656		ADDI	\$1 -1
1600		EXCH	\$10 \$9	1657		EXCH	\$7 \$1
1601		ADDI	\$10 3	1658		ADDI	\$1 -1
1602		EXCH	\$11 \$10	1659		BRA	l_malloc
1603		XOR	\$12 \$11	1660		ADDI	\$1 1
1604		EXCH	\$11 \$10	1661		EXCH	\$7 \$1
1605		ADDI	\$10 -3	1662		ADDI	\$1 1
1606	loadMetAdd_202_i:	EXCH	\$10 \$9	1663		EXCH	\$8 \$1
1607		XOR	\$9 \$8	1664	obj_con_208_i:	ADDI	\$8 -4
1608		ADD	\$7 \$3	1665		ADDI	\$1 1
1609		ADDI	\$7 2	1666		EXCH	\$3 \$1
1610		EXCH	\$8 \$7	1667		ADD	\$6 \$3
1611		ADDI	\$7 -2	1668		ADDI	\$6 3
1612		SUB	\$7 \$3	1669		XORI	\$8 5
1613		XORI	\$6 1	1670		EXCH	\$8 \$7
1614	assert_true_195:	BRA	assert_197	1671		ADDI	\$7 1
1615	test_false_196:	BRA	test_194	1672		XORI	\$8 1
1616	assert_197:	BNE	\$6 \$0	1673		EXCH	\$8 \$7
	assert_true_195			1674	obj_con_208_bot:	ADDI	\$7 -1
1617		ADD	\$7 \$3	1675		EXCH	\$7 \$6
1618		ADDI	\$7 2	1676		ADDI	\$6 -3
1619		EXCH	\$8 \$7	1677		SUB	\$6 \$3
1620		ADDI	\$7 -2	1678		ADD	\$6 \$3
1621		SUB	\$7 \$3	1679		ADDI	\$6 4
1622	cmp_top_204:	BEQ	\$8 \$0	1680		EXCH	\$7 \$6
	cmp_bot_205			1681		ADDI	\$6 -4
1623		XORI	\$9 1	1682		SUB	\$6 \$3
1624	cmp_bot_205:	BEQ	\$8 \$0	1683		XORI	\$8 3
	cmp_top_204			1684		ADD	\$7 \$8
1625	f_top_206:	BEQ	\$9 \$0	1685		XORI	\$8 3
	f_bot_207			1686		ADD	\$6 \$3
1626		XORI	\$10 1	1687		ADDI	\$6 4
1627	f_bot_207:	BEQ	\$9 \$0	1688		EXCH	\$7 \$6
	f_top_206			1689		ADDI	\$6 -4
1628		XOR	\$6 \$10	1690		SUB	\$6 \$3
1629	f_bot_207_i:	BEQ	\$9 \$0	1691	localBlock_227:	XOR	\$6 \$1
	f_top_206_i			1692		XOR	\$7 \$0

1693		EXCH	\$7 \$1	1742		EXCH	\$3 \$1
1694		ADDI	\$1 -1	1743		ADDI	\$1 -1
1695		XORI	\$7 1	1744		EXCH	\$8 \$1
1696	entry_209:	BEQ	\$7 \$0	1745		ADDI	\$1 -1
	assert_211			1746		EXCH	\$6 \$1
1697		EXCH	\$8 \$6	1747		ADDI	\$1 -1
1698	cmp_top_213:	BNE	\$8 \$0	1748	obj_con_217:	ADDI	\$10 8
	cmp_bot_214			1749		EXCH	\$10 \$1
1699		XORI	\$9 1	1750		ADDI	\$1 -1
1700	cmp_bot_214:	BNE	\$8 \$0	1751		EXCH	\$9 \$1
	cmp_top_213			1752		ADDI	\$1 -1
1701	f_top_215:	BEQ	\$9 \$0	1753		BRA	l_malloc
	f_bot_216			1754		ADDI	\$1 1
1702		XORI	\$10 1	1755		EXCH	\$9 \$1
1703	f_bot_216:	BEQ	\$9 \$0	1756		ADDI	\$1 1
	f_top_215			1757		EXCH	\$10 \$1
1704		XOR	\$7 \$10	1758	obj_con_217_i:	ADDI	\$10 -8
1705	f_bot_216_i:	BEQ	\$9 \$0	1759		ADDI	\$1 1
	f_top_215_i			1760		EXCH	\$6 \$1
1706		XORI	\$10 1	1761		ADDI	\$1 1
1707	f_top_215_i:	BEQ	\$9 \$0	1762		EXCH	\$8 \$1
	f_bot_216_i			1763		ADDI	\$1 1
1708	cmp_bot_214_i:	BNE	\$8 \$0	1764		EXCH	\$3 \$1
	cmp_top_213_i			1765		XORI	\$10 8
1709		XORI	\$9 1	1766		EXCH	\$10 \$9
1710	cmp_top_213_i:	BNE	\$8 \$0	1767		ADDI	\$9 1
	cmp_bot_214_i			1768		XORI	\$10 1
1711		EXCH	\$8 \$6	1769		EXCH	\$10 \$9
1712		EXCH	\$8 \$6	1770	obj_con_217_bot:	ADDI	\$9 -1
1713		ADD	\$9 \$3	1771		EXCH	\$9 \$8
1714		ADDI	\$9 4	1772		EXCH	\$9 \$8
1715		EXCH	\$10 \$9	1773		XOR	\$10 \$9
1716		ADDI	\$9 -4	1774	loadMetAdd_218:	EXCH	\$11 \$10
1717		SUB	\$9 \$3	1775		ADDI	\$11 0
1718	cmp_top_223:	BNE	\$8 \$10	1776		EXCH	\$12 \$11
	cmp_bot_224			1777		XOR	\$13 \$12
1719		XORI	\$11 1	1778		EXCH	\$12 \$11
1720	cmp_bot_224:	BNE	\$8 \$10	1779		ADDI	\$11 0
	cmp_top_223			1780		EXCH	\$11 \$10
1721	f_top_225:	BEQ	\$11 \$0	1781		EXCH	\$9 \$8
	f_bot_226			1782		EXCH	\$3 \$1
1722		XORI	\$12 1	1783		ADDI	\$1 -1
1723	f_bot_226:	BEQ	\$11 \$0	1784		EXCH	\$8 \$1
	f_top_225			1785		ADDI	\$1 -1
1724		XOR	\$7 \$12	1786		EXCH	\$6 \$1
1725	f_bot_226_i:	BEQ	\$11 \$0	1787		ADDI	\$1 -1
	f_top_225_i			1788		EXCH	\$10 \$1
1726		XORI	\$12 1	1789		ADDI	\$1 -1
1727	f_top_225_i:	BEQ	\$11 \$0	1790		ADDI	\$13 -1789
	f_bot_226_i			1791	l_jump_219:	SWAPBR	\$13
1728	cmp_bot_224_i:	BNE	\$8 \$10	1792		NEG	\$13
	cmp_top_223_i			1793		ADDI	\$13 1789
1729		XORI	\$11 1	1794		ADDI	\$1 1
1730	cmp_top_223_i:	BNE	\$8 \$10	1795		EXCH	\$10 \$1
	cmp_bot_224_i			1796		ADDI	\$1 1
1731		ADD	\$9 \$3	1797		EXCH	\$6 \$1
1732		ADDI	\$9 4	1798		ADDI	\$1 1
1733		EXCH	\$10 \$9	1799		EXCH	\$8 \$1
1734		ADDI	\$9 -4	1800		ADDI	\$1 1
1735		SUB	\$9 \$3	1801		EXCH	\$3 \$1
1736		EXCH	\$8 \$6	1802		EXCH	\$9 \$8
1737	test_210:	BNE	\$7 \$0 exit_210	1803		EXCH	\$11 \$10
1738	localBlock_222:	XOR	\$8 \$1	1804		ADDI	\$11 0
1739		XOR	\$9 \$0	1805		EXCH	\$12 \$11
1740		EXCH	\$9 \$1	1806		XOR	\$13 \$12
1741		ADDI	\$1 -1	1807		EXCH	\$12 \$11

1808		ADDI	\$11 0	1874		ADD	\$8 \$9
1809	loadMetAdd_218_i:	EXCH	\$11 \$10	1875		XORI	\$9 1
1810		XOR	\$10 \$9	1876		EXCH	\$8 \$6
1811		EXCH	\$9 \$8	1877	assert_211:	BRA	entry_209
1812		ADD	\$9 \$3	1878	exit_212:	BRA	test_210
1813		ADDI	\$9 3	1879		XORI	\$7 1
1814		EXCH	\$10 \$9	1880		ADD	\$7 \$3
1815		ADDI	\$9 -3	1881		ADDI	\$7 4
1816		SUB	\$9 \$3	1882		EXCH	\$8 \$7
1817		XOR	\$11 \$10	1883		ADDI	\$7 -4
1818	loadMetAdd_220:	EXCH	\$12 \$11	1884		SUB	\$7 \$3
1819		ADDI	\$12 0	1885		ADDI	\$1 1
1820		EXCH	\$13 \$12	1886		EXCH	\$9 \$1
1821		XOR	\$14 \$13	1887		XOR	\$9 \$8
1822		EXCH	\$13 \$12	1888	localBlock_227_i:	XOR	\$6 \$1
1823		ADDI	\$12 0	1889		ADD	\$7 \$3
1824		EXCH	\$12 \$11	1890		ADDI	\$7 4
1825		ADD	\$9 \$3	1891		EXCH	\$8 \$7
1826		ADDI	\$9 3	1892		ADDI	\$7 -4
1827		EXCH	\$10 \$9	1893		SUB	\$7 \$3
1828		ADDI	\$9 -3	1894		ADD	\$6 \$3
1829		SUB	\$9 \$3	1895		ADDI	\$6 3
1830		EXCH	\$3 \$1	1896		EXCH	\$7 \$6
1831		ADDI	\$1 -1	1897		ADDI	\$6 -3
1832		EXCH	\$8 \$1	1898		SUB	\$6 \$3
1833		ADDI	\$1 -1	1899		XOR	\$8 \$7
1834		EXCH	\$6 \$1	1900	loadMetAdd_228:	EXCH	\$9 \$8
1835		ADDI	\$1 -1	1901		ADDI	\$9 1
1836		EXCH	\$11 \$1	1902		EXCH	\$10 \$9
1837		ADDI	\$1 -1	1903		XOR	\$11 \$10
1838		ADDI	\$14 -1837	1904		EXCH	\$10 \$9
1839	l_jump_221:	SWAPBR	\$14	1905		ADDI	\$9 -1
1840		NEG	\$14	1906		EXCH	\$9 \$8
1841		ADDI	\$14 1837	1907		ADD	\$6 \$3
1842		ADDI	\$1 1	1908		ADDI	\$6 3
1843		EXCH	\$11 \$1	1909		EXCH	\$7 \$6
1844		ADDI	\$1 1	1910		ADDI	\$6 -3
1845		EXCH	\$6 \$1	1911		SUB	\$6 \$3
1846		ADDI	\$1 1	1912		ADD	\$12 \$3
1847		EXCH	\$8 \$1	1913		ADDI	\$12 2
1848		ADDI	\$1 1	1914		EXCH	\$3 \$1
1849		EXCH	\$3 \$1	1915		ADDI	\$1 -1
1850		ADD	\$9 \$3	1916		EXCH	\$12 \$1
1851		ADDI	\$9 3	1917		ADDI	\$1 -1
1852		EXCH	\$10 \$9	1918		EXCH	\$8 \$1
1853		ADDI	\$9 -3	1919		ADDI	\$1 -1
1854		SUB	\$9 \$3	1920		ADDI	\$11 -1919
1855		EXCH	\$12 \$11	1921	l_jump_229:	SWAPBR	\$11
1856		ADDI	\$12 0	1922		NEG	\$11
1857		EXCH	\$13 \$12	1923		ADDI	\$11 1919
1858		XOR	\$14 \$13	1924		ADDI	\$1 1
1859		EXCH	\$13 \$12	1925		EXCH	\$8 \$1
1860		ADDI	\$12 0	1926		ADDI	\$1 1
1861	loadMetAdd_220_i:	EXCH	\$12 \$11	1927		EXCH	\$12 \$1
1862		XOR	\$11 \$10	1928		ADDI	\$1 1
1863		ADD	\$9 \$3	1929		EXCH	\$3 \$1
1864		ADDI	\$9 3	1930		ADDI	\$12 -2
1865		EXCH	\$10 \$9	1931		SUB	\$12 \$3
1866		ADDI	\$9 -3	1932		ADD	\$6 \$3
1867		SUB	\$9 \$3	1933		ADDI	\$6 3
1868		ADDI	\$1 1	1934		EXCH	\$7 \$6
1869		EXCH	\$9 \$1	1935		ADDI	\$6 -3
1870		XOR	\$9 \$0	1936		SUB	\$6 \$3
1871	localBlock_222_i:	XOR	\$8 \$1	1937		EXCH	\$9 \$8
1872		EXCH	\$8 \$6	1938		ADDI	\$9 1
1873		XORI	\$9 1	1939		EXCH	\$10 \$9

1940		XOR	\$11 \$10	1999	start:	BRA	top
1941		EXCH	\$10 \$9	2000		START	
1942		ADDI	\$9 -1	2001		ADDI	\$4 2055
1943	loadMetAdd_228_i:	EXCH	\$9 \$8	2002		XOR	\$5 \$4
1944		XOR	\$8 \$7	2003		ADDI	\$5 10
1945		ADD	\$6 \$3	2004		XOR	\$7 \$5
1946		ADDI	\$6 3	2005		ADDI	\$4 10
1947		EXCH	\$7 \$6	2006		ADDI	\$4 -1
1948		ADDI	\$6 -3	2007		EXCH	\$7 \$4
1949		SUB	\$6 \$3	2008		ADDI	\$4 1
1950		ADD	\$6 \$3	2009		ADDI	\$4 -10
1951		ADDI	\$6 3	2010		XOR	\$1 \$5
1952		EXCH	\$7 \$6	2011		ADDI	\$1 2048
1953		ADDI	\$6 -3	2012		ADDI	\$1 -8
1954		SUB	\$6 \$3	2013		XOR	\$3 \$1
1955		XOR	\$8 \$7	2014		XORI	\$6 4
1956	loadMetAdd_230:	EXCH	\$9 \$8	2015		EXCH	\$6 \$3
1957		ADDI	\$9 2	2016		ADDI	\$1 -1
1958		EXCH	\$10 \$9	2017		EXCH	\$3 \$1
1959		XOR	\$11 \$10	2018		ADDI	\$1 -1
1960		EXCH	\$10 \$9	2019		BRA	l_main_0
1961		ADDI	\$9 -2	2020		ADDI	\$1 1
1962		EXCH	\$9 \$8	2021		EXCH	\$3 \$1
1963		ADD	\$6 \$3	2022		ADDI	\$3 1
1964		ADDI	\$6 3	2023		ADDI	\$3 1
1965		EXCH	\$7 \$6	2024		EXCH	\$6 \$3
1966		ADDI	\$6 -3	2025		XORI	\$7 1
1967		SUB	\$6 \$3	2026		EXCH	\$6 \$7
1968		EXCH	\$3 \$1	2027		XORI	\$7 1
1969		ADDI	\$1 -1	2028		ADDI	\$3 -1
1970		EXCH	\$8 \$1	2029		ADDI	\$3 -1
1971		ADDI	\$1 -1	2030		ADDI	\$3 1
1972		ADDI	\$11 -1971	2031		ADDI	\$3 2
1973	l_jump_231:	SWAPBR	\$11	2032		EXCH	\$6 \$3
1974		NEG	\$11	2033		XORI	\$7 2
1975		ADDI	\$11 1971	2034		EXCH	\$6 \$7
1976		ADDI	\$1 1	2035		XORI	\$7 2
1977		EXCH	\$8 \$1	2036		ADDI	\$3 -2
1978		ADDI	\$1 1	2037		ADDI	\$3 -1
1979		EXCH	\$3 \$1	2038		ADDI	\$3 1
1980		ADD	\$6 \$3	2039		ADDI	\$3 3
1981		ADDI	\$6 3	2040		EXCH	\$6 \$3
1982		EXCH	\$7 \$6	2041		XORI	\$7 3
1983		ADDI	\$6 -3	2042		EXCH	\$6 \$7
1984		SUB	\$6 \$3	2043		XORI	\$7 3
1985		EXCH	\$9 \$8	2044		ADDI	\$3 -3
1986		ADDI	\$9 2	2045		ADDI	\$3 -1
1987		EXCH	\$10 \$9	2046		ADDI	\$1 1
1988		XOR	\$11 \$10	2047		EXCH	\$6 \$3
1989		EXCH	\$10 \$9	2048		XORI	\$6 4
1990		ADDI	\$9 -2	2049		XOR	\$3 \$1
1991	loadMetAdd_230_i:	EXCH	\$9 \$8	2050		ADDI	\$1 8
1992		XOR	\$8 \$7	2051		ADDI	\$1 -2048
1993		ADD	\$6 \$3	2052		XOR	\$1 \$5
1994		ADDI	\$6 3	2053		ADDI	\$5 -10
1995		EXCH	\$7 \$6	2054		XOR	\$5 \$4
1996		ADDI	\$6 -3	2055		ADDI	\$4 -2055
1997		SUB	\$6 \$3	2056	finish:	FINISH	
1998	l_main_0_bot:	BRA	l_main_0_top				

DoublyLinkedList.rplpp

```
1 class Cell
2     int data
3     int index
4     Cell left
5     Cell right
6     Cell self
7
8     method setData(int value)
9         data ^= value
10
11     method setIndex(int i)
12         index ^= i
13
14     method setLeft(Cell cell)
15         left <=> cell
16
17     method setRight(Cell cell)
18         right <=> cell
19
20     method setSelf(Cell cell)
21         self <=> cell
22
23     method append(Cell cell)
24         if right = nil & cell != nil then // If current cell does not have a right neighbour
25             right <=> cell // Set new cell as right neighbour of current cell
26
27             local Cell selfCopy = nil
28             copy Cell self selfCopy // Copy reference to current cell
29             call right::setLeft(selfCopy) // Set current cell as left neighbour of newly
30                 added right neighbour
31             delocal Cell selfCopy = nil
32
33             local int cellIndex = index + 1
34             call right::setIndex(cellIndex) // Set cell index in newly added right neighbour
35                 of current cell
36             delocal int cellIndex = index + 1
37
38         else skip
39         fi right != nil & cell = nil
40
41         if right != nil then
42             call right::append(cell) // Keep searching for empty right neighbour
43         else skip
44         fi right != nil
45
46 class DoublyLinkedList
47     Cell head
48     int length
49
50     method appendCell(Cell cell)
51         if head = nil & cell != nil then
52             head <=> cell
53         else skip
54         fi head != nil & cell = nil
55
56         if head != nil then
57             call head::append(cell)
58         else skip
59         fi head != nil
60
61         length += 1
62
63 class Program
64     DoublyLinkedList list
```

```

62  int listLength
63
64  method main()
65      new DoublyLinkedList list
66      listLength += 10
67
68      local int x = 0
69      from x = 0 do skip
70      loop
71          local Cell cell = nil
72          new Cell cell
73
74          local Cell cellCopy = nil
75          copy Cell cell cellCopy
76          call cell::setSelf(cellCopy)
77          delocal Cell cellCopy = nil
78
79          call cell::setData(x)
80          call list::appendCell(cell)
81          delocal Cell cell = nil
82          x += 1
83      until x = listLength
84      delocal int x = listLength

```

DoublyLinkedList.pal

```

1  ;; pendulum pal file                                60
2  top:          BRA    start                            61
3  l_r_list:     DATA  0                                62
4  l_r_listLength: DATA  0                                63
5  l_Program_vt: DATA  977                              64
6  l_DoublyLinkedList_vt: DATA  759                      65
7  l_Cell_vt:    DATA  223                              66
8               DATA  252                              67
9               DATA  281                              68
10              DATA  312                              69
11              DATA  343                              70
12              DATA  374                              71
13 l_malloc_top: BRA    l_malloc_bot                      72
14 l_malloc:     SWAPBR $2                                73
15              NEG    $2                                74
16              ADDI   $9 2                               75
17              XOR    $8 $0                             76
18              ADDI   $1 1                               77
19              EXCH   $6 $1                             78
20              ADDI   $1 1                               79
21              EXCH   $7 $1                             80
22              EXCH   $2 $1                             81
23              ADDI   $1 -1                             82
24              BRA    l_malloc1                          83
25              ADDI   $1 1                               84
26              EXCH   $2 $1                             85
27              EXCH   $7 $1                             86
28              ADDI   $1 -1                             87
29              EXCH   $6 $1                             88
30              ADDI   $1 -1                             89
31              XOR    $8 $0                             90
32              ADDI   $9 -2                             91
33 l_malloc_bot: BRA    l_malloc_top                      92
34 l_malloc1_top: BRA    l_malloc1_bot                    93
35              ADDI   $1 1                               94
36              EXCH   $2 $1                             95
37              SUB    $17 $8                             96
38              XOR    $17 $4                             97
39 l_malloc1:    SWAPBR $2                                98
40              NEG    $2                                99
41              EXCH   $2 $1                             100
42              ADDI   $1 -1                             101
43              XOR    $17 $4                             102
44              ADD    $17 $8                             103
45              EXCH   $19 $17                            104
46              XOR    $18 $19                            105
47              EXCH   $19 $17                            106
48              XOR    $13 $9                             107
49              SUB    $13 $7                             108
50 cmp_top_8:    BGEZ   $13 cmp_bot_9                     109
51              XORI   $14 1                              110
52 cmp_bot_9:    BGEZ   $13 cmp_top_8                     111
53              XOR    $10 $14                            112
54 cmp_bot_9_i:  BGEZ   $13                              113
55              cmp_top_8_i                                114
56 cmp_top_8_i:  BGEZ   $13                              115
57              cmp_bot_9_i                                116
58              ADD    $13 $7                              117
59              XOR    $13 $9                              118
l_o_test:      BEQ    $10 $0                             119
              l_o_test_false

```

```

XORI    $10 1
ADDI    $8 1
EXCH    $19 $17
XOR     $18 $19
EXCH    $19 $17
RL      $9 1
EXCH    $10 $1
ADDI    $1 -1
EXCH    $11 $1
ADDI    $1 -1
EXCH    $12 $1
ADDI    $1 -1
EXCH    $14 $1
ADDI    $1 -1
EXCH    $16 $1
ADDI    $1 -1
EXCH    $17 $1
ADDI    $1 -1
EXCH    $18 $1
ADDI    $1 -1
EXCH    $20 $1
ADDI    $1 -1
EXCH    $21 $1
ADDI    $1 -1
EXCH    $22 $1
ADDI    $1 -1
EXCH    $23 $1
ADDI    $1 -1
BRA     l_malloc1
ADDI    $1 1
EXCH    $23 $1
ADDI    $1 1
EXCH    $22 $1
ADDI    $1 1
EXCH    $20 $1
ADDI    $1 1
EXCH    $18 $1
ADDI    $1 1
EXCH    $17 $1
ADDI    $1 1
EXCH    $16 $1
ADDI    $1 1
EXCH    $14 $1
ADDI    $1 1
EXCH    $12 $1
ADDI    $1 1
EXCH    $11 $1
ADDI    $8 -1
XORI    $10 1
BRA     l_o_assert
BRA     l_o_test
BEQ     $18 $0
XORI    $20 1
BEQ     $18 $0
XOR     $11 $20

```

120	cmp_bot_13_i:	BEQ	\$18 \$0	183		EXCH	\$12 \$17
	cmp_top_12_i			184		ADD	\$6 \$9
121		XORI	\$20 1	185	l_i_assert:	BNE	\$11 \$0
122	cmp_top_12_i:	BEQ	\$18 \$0		l_i_assert_true		
	cmp_bot_13_i			186		EXCH	\$12 \$17
123	l_i_test:	BEQ	\$11 \$0	187		SUB	\$6 \$9
	l_i_test_false			188	cmp_top_14:	BEQ	\$6 \$12
124		XORI	\$11 1		cmp_bot_15		
125		ADD	\$6 \$18	189		XORI	\$21 1
126		SUB	\$18 \$6	190	cmp_bot_15:	BEQ	\$6 \$12
127		EXCH	\$12 \$6		cmp_top_14		
128		EXCH	\$12 \$17	191	cmp_top_16:	BNE	\$12 \$0
129		XOR	\$12 \$6		cmp_bot_17		
130		XORI	\$11 1	192		XORI	\$22 1
131	l_i_assert_true:	BRA	l_i_assert	193	cmp_bot_17:	BNE	\$12 \$0
132	l_i_test_false:	BRA	l_i_test		cmp_top_16		
133		ADDI	\$8 1	194		ORX	\$23 \$21 \$22
134		RL	\$9 1	195		XOR	\$11 \$23
135		EXCH	\$10 \$1	196		ORX	\$23 \$21 \$22
136		ADDI	\$1 -1	197	cmp_bot_17_i:	BNE	\$12 \$0
137		EXCH	\$11 \$1		cmp_top_16_i		
138		ADDI	\$1 -1	198		XORI	\$22 1
139		EXCH	\$12 \$1	199	cmp_top_16_i:	BNE	\$12 \$0
140		ADDI	\$1 -1		cmp_bot_17_i		
141		EXCH	\$14 \$1	200	cmp_bot_15_i:	BEQ	\$6 \$12
142		ADDI	\$1 -1		cmp_top_14_i		
143		EXCH	\$16 \$1	201		XORI	\$21 1
144		ADDI	\$1 -1	202	cmp_top_14_i:	BEQ	\$6 \$12
145		EXCH	\$17 \$1		cmp_bot_15_i		
146		ADDI	\$1 -1	203		ADD	\$6 \$9
147		EXCH	\$18 \$1	204		EXCH	\$12 \$17
148		ADDI	\$1 -1	205	l_o_assert:	BNE	\$10 \$0
149		EXCH	\$20 \$1		l_o_assert_true		
150		ADDI	\$1 -1	206		XOR	\$15 \$9
151		EXCH	\$21 \$1	207		SUB	\$15 \$7
152		ADDI	\$1 -1	208	cmp_top_10:	BGEZ	\$15 cmp_bot_11
153		EXCH	\$22 \$1	209		XORI	\$16 1
154		ADDI	\$1 -1	210	cmp_bot_11:	BGEZ	\$15 cmp_top_10
155		EXCH	\$23 \$1	211		XOR	\$10 \$16
156		ADDI	\$1 -1	212	cmp_bot_11_i:	BGEZ	\$15
157		BRA	l_malloc1		cmp_top_10_i		
158		ADDI	\$1 1	213		XORI	\$16 1
159		EXCH	\$23 \$1	214	cmp_top_10_i:	BGEZ	\$15
160		ADDI	\$1 1		cmp_bot_11_i		
161		EXCH	\$22 \$1	215		ADD	\$15 \$7
162		ADDI	\$1 1	216		XOR	\$15 \$9
163		EXCH	\$21 \$1	217	l_malloc1_bot:	BRA	l_malloc1_top
164		ADDI	\$1 1	218	l_setData_2_top:	BRA	
165		EXCH	\$20 \$1		l_setData_2_bot		
166		ADDI	\$1 1	219		ADDI	\$1 1
167		EXCH	\$18 \$1	220		EXCH	\$2 \$1
168		ADDI	\$1 1	221		EXCH	\$6 \$1
169		EXCH	\$17 \$1	222		ADDI	\$1 -1
170		ADDI	\$1 1	223		EXCH	\$3 \$1
171		EXCH	\$16 \$1	224		ADDI	\$1 -1
172		ADDI	\$1 1	225	l_setData_2:	SWAPBR	\$2
173		EXCH	\$14 \$1	226		NEG	\$2
174		ADDI	\$1 1	227		ADDI	\$1 1
175		EXCH	\$12 \$1	228		EXCH	\$3 \$1
176		ADDI	\$1 1	229		ADDI	\$1 1
177		EXCH	\$11 \$1	230		EXCH	\$6 \$1
178		ADDI	\$1 1	231		EXCH	\$2 \$1
179		EXCH	\$10 \$1	232		ADDI	\$1 -1
180		RR	\$9 1	233		ADD	\$7 \$3
181		ADDI	\$8 -1	234		ADDI	\$7 2
182		XOR	\$12 \$6	235		EXCH	\$8 \$7

236		ADDI	\$7 -2	298		XOR	\$9 \$8
237		SUB	\$7 \$3	299		XOR	\$8 \$9
238		EXCH	\$9 \$6	300		EXCH	\$9 \$6
239		XOR	\$8 \$9	301		ADD	\$7 \$3
240		EXCH	\$9 \$6	302		ADDI	\$7 4
241		ADD	\$7 \$3	303		EXCH	\$8 \$7
242		ADDI	\$7 2	304		ADDI	\$7 -4
243		EXCH	\$8 \$7	305		SUB	\$7 \$3
244		ADDI	\$7 -2	306	l_setLeft_4_bot:	BRA	
245		SUB	\$7 \$3		l_setLeft_4_top		
246	l_setData_2_bot:	BRA		307	l_setRight_5_top:	BRA	
	l_setData_2_top				l_setRight_5_bot		
247	l_setIndex_3_top:	BRA		308		ADDI	\$1 1
	l_setIndex_3_bot			309		EXCH	\$2 \$1
248		ADDI	\$1 1	310		EXCH	\$6 \$1
249		EXCH	\$2 \$1	311		ADDI	\$1 -1
250		EXCH	\$6 \$1	312		EXCH	\$3 \$1
251		ADDI	\$1 -1	313		ADDI	\$1 -1
252		EXCH	\$3 \$1	314	l_setRight_5:	SWAPBR	\$2
253		ADDI	\$1 -1	315		NEG	\$2
254	l_setIndex_3:	SWAPBR	\$2	316		ADDI	\$1 1
255		NEG	\$2	317		EXCH	\$3 \$1
256		ADDI	\$1 1	318		ADDI	\$1 1
257		EXCH	\$3 \$1	319		EXCH	\$6 \$1
258		ADDI	\$1 1	320		EXCH	\$2 \$1
259		EXCH	\$6 \$1	321		ADDI	\$1 -1
260		EXCH	\$2 \$1	322		ADD	\$7 \$3
261		ADDI	\$1 -1	323		ADDI	\$7 5
262		ADD	\$7 \$3	324		EXCH	\$8 \$7
263		ADDI	\$7 3	325		ADDI	\$7 -5
264		EXCH	\$8 \$7	326		SUB	\$7 \$3
265		ADDI	\$7 -3	327		EXCH	\$9 \$6
266		SUB	\$7 \$3	328	swap_19:	XOR	\$8 \$9
267		EXCH	\$9 \$6	329		XOR	\$9 \$8
268		XOR	\$8 \$9	330		XOR	\$8 \$9
269		EXCH	\$9 \$6	331		EXCH	\$9 \$6
270		ADD	\$7 \$3	332		ADD	\$7 \$3
271		ADDI	\$7 3	333		ADDI	\$7 5
272		EXCH	\$8 \$7	334		EXCH	\$8 \$7
273		ADDI	\$7 -3	335		ADDI	\$7 -5
274		SUB	\$7 \$3	336		SUB	\$7 \$3
275	l_setIndex_3_bot:	BRA		337	l_setRight_5_bot:	BRA	
	l_setIndex_3_top				l_setRight_5_top		
276	l_setLeft_4_top:	BRA		338	l_setSelf_6_top:	BRA	
	l_setLeft_4_bot				l_setSelf_6_bot		
277		ADDI	\$1 1	339		ADDI	\$1 1
278		EXCH	\$2 \$1	340		EXCH	\$2 \$1
279		EXCH	\$6 \$1	341		EXCH	\$6 \$1
280		ADDI	\$1 -1	342		ADDI	\$1 -1
281		EXCH	\$3 \$1	343		EXCH	\$3 \$1
282		ADDI	\$1 -1	344		ADDI	\$1 -1
283	l_setLeft_4:	SWAPBR	\$2	345	l_setSelf_6:	SWAPBR	\$2
284		NEG	\$2	346		NEG	\$2
285		ADDI	\$1 1	347		ADDI	\$1 1
286		EXCH	\$3 \$1	348		EXCH	\$3 \$1
287		ADDI	\$1 1	349		ADDI	\$1 1
288		EXCH	\$6 \$1	350		EXCH	\$6 \$1
289		EXCH	\$2 \$1	351		EXCH	\$2 \$1
290		ADDI	\$1 -1	352		ADDI	\$1 -1
291		ADD	\$7 \$3	353		ADD	\$7 \$3
292		ADDI	\$7 4	354		ADDI	\$7 6
293		EXCH	\$8 \$7	355		EXCH	\$8 \$7
294		ADDI	\$7 -4	356		ADDI	\$7 -6
295		SUB	\$7 \$3	357		SUB	\$7 \$3
296		EXCH	\$9 \$6	358		EXCH	\$9 \$6
297	swap_18:	XOR	\$8 \$9	359	swap_20:	XOR	\$8 \$9

360		XOR	\$9 \$8	413		ADDI	\$8 5
361		XOR	\$8 \$9	414		EXCH	\$9 \$8
362		EXCH	\$9 \$6	415		ADDI	\$8 -5
363		ADD	\$7 \$3	416		SUB	\$8 \$3
364		ADDI	\$7 6	417	test_21:	BEQ	\$7 \$0
365		EXCH	\$8 \$7		test_false_23		
366		ADDI	\$7 -6	418		XORI	\$7 1
367		SUB	\$7 \$3	419		ADD	\$8 \$3
368	l_setSelf_6_bot:	BRA		420		ADDI	\$8 5
	l_setSelf_6_top			421		EXCH	\$9 \$8
369	l_append_7_top:	BRA	l_append_7_bot	422		ADDI	\$8 -5
370		ADDI	\$1 1	423		SUB	\$8 \$3
371		EXCH	\$2 \$1	424		EXCH	\$10 \$6
372		EXCH	\$6 \$1	425	swap_31:	XOR	\$9 \$10
373		ADDI	\$1 -1	426		XOR	\$10 \$9
374		EXCH	\$3 \$1	427		XOR	\$9 \$10
375		ADDI	\$1 -1	428		EXCH	\$10 \$6
376	l_append_7:	SWAPBR	\$2	429		ADD	\$8 \$3
377		NEG	\$2	430		ADDI	\$8 5
378		ADDI	\$1 1	431		EXCH	\$9 \$8
379		EXCH	\$3 \$1	432		ADDI	\$8 -5
380		ADDI	\$1 1	433		SUB	\$8 \$3
381		EXCH	\$6 \$1	434	localBlock_35:	XOR	\$8 \$1
382		EXCH	\$2 \$1	435		XOR	\$9 \$0
383		ADDI	\$1 -1	436		EXCH	\$9 \$1
384		ADD	\$8 \$3	437		ADDI	\$1 -1
385		ADDI	\$8 5	438		EXCH	\$9 \$8
386		EXCH	\$9 \$8	439		ADD	\$10 \$3
387		ADDI	\$8 -5	440		ADDI	\$10 6
388		SUB	\$8 \$3	441		EXCH	\$11 \$10
389	cmp_top_25:	BNE	\$9 \$0	442		ADDI	\$10 -6
	cmp_bot_26			443		SUB	\$10 \$3
390		XORI	\$10 1	444	copy_32:	XOR	\$9 \$11
391	cmp_bot_26:	BNE	\$9 \$0	445		ADDI	\$11 1
	cmp_top_25			446		EXCH	\$12 \$11
392		EXCH	\$11 \$6	447		ADDI	\$12 1
393	cmp_top_27:	BEQ	\$11 \$0	448		EXCH	\$12 \$11
	cmp_bot_28			449		ADDI	\$11 -1
394		XORI	\$12 1	450		ADD	\$10 \$3
395	cmp_bot_28:	BEQ	\$11 \$0	451		ADDI	\$10 6
	cmp_top_27			452		EXCH	\$11 \$10
396		ANDX	\$13 \$10 \$12	453		ADDI	\$10 -6
397	f_top_29:	BEQ	\$13 \$0	454		SUB	\$10 \$3
	f_bot_30			455		EXCH	\$9 \$8
398		XORI	\$14 1	456		ADD	\$9 \$3
399	f_bot_30:	BEQ	\$13 \$0	457		ADDI	\$9 5
	f_top_29			458		EXCH	\$10 \$9
400		XOR	\$7 \$14	459		ADDI	\$9 -5
401	f_bot_30_i:	BEQ	\$13 \$0	460		SUB	\$9 \$3
	f_top_29_i			461		XOR	\$11 \$10
402		XORI	\$14 1	462	loadMetAdd_33:	EXCH	\$12 \$11
403	f_top_29_i:	BEQ	\$13 \$0	463		ADDI	\$12 2
	f_bot_30_i			464		EXCH	\$13 \$12
404		ANDX	\$13 \$10 \$12	465		XOR	\$14 \$13
405	cmp_bot_28_i:	BEQ	\$11 \$0	466		EXCH	\$13 \$12
	cmp_top_27_i			467		ADDI	\$12 -2
406		XORI	\$12 1	468		EXCH	\$12 \$11
407	cmp_top_27_i:	BEQ	\$11 \$0	469		ADD	\$9 \$3
	cmp_bot_28_i			470		ADDI	\$9 5
408		EXCH	\$11 \$6	471		EXCH	\$10 \$9
409	cmp_bot_26_i:	BNE	\$9 \$0	472		ADDI	\$9 -5
	cmp_top_25_i			473		SUB	\$9 \$3
410		XORI	\$10 1	474		EXCH	\$3 \$1
411	cmp_top_25_i:	BNE	\$9 \$0	475		ADDI	\$1 -1
	cmp_bot_26_i			476		EXCH	\$6 \$1
412		ADD	\$8 \$3	477		ADDI	\$1 -1

478		EXCH	\$8 \$1	544	EXCH	\$13 \$12
479		ADDI	\$1 -1	545	XOR	\$14 \$13
480		EXCH	\$11 \$1	546	EXCH	\$13 \$12
481		ADDI	\$1 -1	547	ADDI	\$12 -1
482		ADDI	\$14 -481	548	EXCH	\$12 \$11
483	l_jump_34:	SWAPBR	\$14	549	ADD	\$9 \$3
484		NEG	\$14	550	ADDI	\$9 5
485		ADDI	\$14 481	551	EXCH	\$10 \$9
486		ADDI	\$1 1	552	ADDI	\$9 -5
487		EXCH	\$11 \$1	553	SUB	\$9 \$3
488		ADDI	\$1 1	554	EXCH	\$3 \$1
489		EXCH	\$8 \$1	555	ADDI	\$1 -1
490		ADDI	\$1 1	556	EXCH	\$6 \$1
491		EXCH	\$6 \$1	557	ADDI	\$1 -1
492		ADDI	\$1 1	558	EXCH	\$8 \$1
493		EXCH	\$3 \$1	559	ADDI	\$1 -1
494		ADD	\$9 \$3	560	EXCH	\$11 \$1
495		ADDI	\$9 5	561	ADDI	\$1 -1
496		EXCH	\$10 \$9	562	ADDI	\$14 -561
497		ADDI	\$9 -5	563	l_jump_37:	SWAPBR
498		SUB	\$9 \$3	564		NEG
499		EXCH	\$12 \$11	565		ADDI
500		ADDI	\$12 2	566		ADDI
501		EXCH	\$13 \$12	567		EXCH
502		XOR	\$14 \$13	568		ADDI
503		EXCH	\$13 \$12	569		EXCH
504		ADDI	\$12 -2	570		ADDI
505	loadMetAdd_33_i:	EXCH	\$12 \$11	571		EXCH
506		XOR	\$11 \$10	572		ADDI
507		ADD	\$9 \$3	573		EXCH
508		ADDI	\$9 5	574		ADD
509		EXCH	\$10 \$9	575		ADDI
510		ADDI	\$9 -5	576		EXCH
511		SUB	\$9 \$3	577		ADDI
512		ADDI	\$1 1	578		SUB
513		EXCH	\$9 \$1	579		EXCH
514		XOR	\$9 \$0	580		ADDI
515	localBlock_35_i:	XOR	\$8 \$1	581		EXCH
516		ADD	\$9 \$3	582		XOR
517		ADDI	\$9 3	583		EXCH
518		EXCH	\$10 \$9	584		ADDI
519		ADDI	\$9 -3	585	loadMetAdd_36_i:	EXCH
520		SUB	\$9 \$3	586		XOR
521		XORI	\$11 1	587		ADD
522		XOR	\$12 \$10	588		ADDI
523		ADD	\$12 \$11	589		EXCH
524	localBlock_38:	XOR	\$8 \$1	590		ADDI
525		XOR	\$13 \$12	591		SUB
526		EXCH	\$13 \$1	592		ADD
527		ADDI	\$1 -1	593		ADDI
528		SUB	\$12 \$11	594		EXCH
529		XOR	\$12 \$10	595		ADDI
530		XORI	\$11 1	596		SUB
531		ADD	\$9 \$3	597		XORI
532		ADDI	\$9 3	598		XOR
533		EXCH	\$10 \$9	599		ADD
534		ADDI	\$9 -3	600		ADDI
535		SUB	\$9 \$3	601		EXCH
536		ADD	\$9 \$3	602		XOR
537		ADDI	\$9 5	603	localBlock_38_i:	XOR
538		EXCH	\$10 \$9	604		SUB
539		ADDI	\$9 -5	605		XOR
540		SUB	\$9 \$3	606		XORI
541		XOR	\$11 \$10	607		ADD
542	loadMetAdd_36:	EXCH	\$12 \$11	608		ADDI
543		ADDI	\$12 1	609		EXCH

610		ADDI	\$9 -3		f_top_51		
611		SUB	\$9 \$3	660		XOR	\$7 \$11
612		XORI	\$7 1	661	f_bot_52_i:	BEQ	\$10 \$0
613	assert_true_22:	BRA	assert_24		f_top_51_i		
614	test_false_23:	BRA	test_21	662		XORI	\$11 1
615	assert_24:	BNE	\$7 \$0	663	f_top_51_i:	BEQ	\$10 \$0
	assert_true_22				f_bot_52_i		
616		ADD	\$8 \$3	664	cmp_bot_50_i:	BEQ	\$9 \$0
617		ADDI	\$8 5		cmp_top_49_i		
618		EXCH	\$9 \$8	665		XORI	\$10 1
619		ADDI	\$8 -5	666	cmp_top_49_i:	BEQ	\$9 \$0
620		SUB	\$8 \$3		cmp_bot_50_i		
621	cmp_top_39:	BEQ	\$9 \$0	667		ADD	\$8 \$3
	cmp_bot_40			668		ADDI	\$8 5
622		XORI	\$10 1	669		EXCH	\$9 \$8
623	cmp_bot_40:	BEQ	\$9 \$0	670		ADDI	\$8 -5
	cmp_top_39			671		SUB	\$8 \$3
624		EXCH	\$11 \$6	672	test_45:	BEQ	\$7 \$0
625	cmp_top_41:	BNE	\$11 \$0		test_false_47		
	cmp_bot_42			673		XORI	\$7 1
626		XORI	\$12 1	674		ADD	\$8 \$3
627	cmp_bot_42:	BNE	\$11 \$0	675		ADDI	\$8 5
	cmp_top_41			676		EXCH	\$9 \$8
628		ANDX	\$13 \$10 \$12	677		ADDI	\$8 -5
629	f_top_43:	BEQ	\$13 \$0	678		SUB	\$8 \$3
	f_bot_44			679		XOR	\$10 \$9
630		XORI	\$14 1	680	loadMetAdd_53:	EXCH	\$11 \$10
631	f_bot_44:	BEQ	\$13 \$0	681		ADDI	\$11 5
	f_top_43			682		EXCH	\$12 \$11
632		XOR	\$7 \$14	683		XOR	\$13 \$12
633	f_bot_44_i:	BEQ	\$13 \$0	684		EXCH	\$12 \$11
	f_top_43_i			685		ADDI	\$11 -5
634		XORI	\$14 1	686		EXCH	\$11 \$10
635	f_top_43_i:	BEQ	\$13 \$0	687		ADD	\$8 \$3
	f_bot_44_i			688		ADDI	\$8 5
636		ANDX	\$13 \$10 \$12	689		EXCH	\$9 \$8
637	cmp_bot_42_i:	BNE	\$11 \$0	690		ADDI	\$8 -5
	cmp_top_41_i			691		SUB	\$8 \$3
638		XORI	\$12 1	692		EXCH	\$3 \$1
639	cmp_top_41_i:	BNE	\$11 \$0	693		ADDI	\$1 -1
	cmp_bot_42_i			694		EXCH	\$6 \$1
640		EXCH	\$11 \$6	695		ADDI	\$1 -1
641	cmp_bot_40_i:	BEQ	\$9 \$0	696		EXCH	\$10 \$1
	cmp_top_39_i			697		ADDI	\$1 -1
642		XORI	\$10 1	698		ADDI	\$13 -697
643	cmp_top_39_i:	BEQ	\$9 \$0	699	l_jump_54:	SWAPBR	\$13
	cmp_bot_40_i			700		NEG	\$13
644		ADD	\$8 \$3	701		ADDI	\$13 697
645		ADDI	\$8 5	702		ADDI	\$1 1
646		EXCH	\$9 \$8	703		EXCH	\$10 \$1
647		ADDI	\$8 -5	704		ADDI	\$1 1
648		SUB	\$8 \$3	705		EXCH	\$6 \$1
649		ADD	\$8 \$3	706		ADDI	\$1 1
650		ADDI	\$8 5	707		EXCH	\$3 \$1
651		EXCH	\$9 \$8	708		ADD	\$8 \$3
652		ADDI	\$8 -5	709		ADDI	\$8 5
653		SUB	\$8 \$3	710		EXCH	\$9 \$8
654	cmp_top_49:	BEQ	\$9 \$0	711		ADDI	\$8 -5
	cmp_bot_50			712		SUB	\$8 \$3
655		XORI	\$10 1	713		EXCH	\$11 \$10
656	cmp_bot_50:	BEQ	\$9 \$0	714		ADDI	\$11 5
	cmp_top_49			715		EXCH	\$12 \$11
657	f_top_51:	BEQ	\$10 \$0	716		XOR	\$13 \$12
	f_bot_52			717		EXCH	\$12 \$11
658		XORI	\$11 1	718		ADDI	\$11 -5
659	f_bot_52:	BEQ	\$10 \$0	719	loadMetAdd_53_i:	EXCH	\$11 \$10

720		XOR	\$10 \$9	775		XORI	\$10 1
721		ADD	\$8 \$3	776	cmp_bot_64:	BNE	\$9 \$0
722		ADDI	\$8 5		cmp_top_63		
723		EXCH	\$9 \$8	777		EXCH	\$11 \$6
724		ADDI	\$8 -5	778	cmp_top_65:	BEQ	\$11 \$0
725		SUB	\$8 \$3		cmp_bot_66		
726		XORI	\$7 1	779		XORI	\$12 1
727	assert_true_46:	BRA	assert_48	780	cmp_bot_66:	BEQ	\$11 \$0
728	test_false_47:	BRA	test_45		cmp_top_65		
729	assert_48:	BNE	\$7 \$0	781		ANDX	\$13 \$10 \$12
	assert_true_46			782	f_top_67:	BEQ	\$13 \$0
730		ADD	\$8 \$3		f_bot_68		
731		ADDI	\$8 5	783		XORI	\$14 1
732		EXCH	\$9 \$8	784	f_bot_68:	BEQ	\$13 \$0
733		ADDI	\$8 -5		f_top_67		
734		SUB	\$8 \$3	785		XOR	\$7 \$14
735	cmp_top_55:	BEQ	\$9 \$0	786	f_bot_68_i:	BEQ	\$13 \$0
	cmp_bot_56				f_top_67_i		
736		XORI	\$10 1	787		XORI	\$14 1
737	cmp_bot_56:	BEQ	\$9 \$0	788	f_top_67_i:	BEQ	\$13 \$0
	cmp_top_55				f_bot_68_i		
738	f_top_57:	BEQ	\$10 \$0	789		ANDX	\$13 \$10 \$12
	f_bot_58			790	cmp_bot_66_i:	BEQ	\$11 \$0
739		XORI	\$11 1		cmp_top_65_i		
740	f_bot_58:	BEQ	\$10 \$0	791		XORI	\$12 1
	f_top_57			792	cmp_top_65_i:	BEQ	\$11 \$0
741		XOR	\$7 \$11		cmp_bot_66_i		
742	f_bot_58_i:	BEQ	\$10 \$0	793		EXCH	\$11 \$6
	f_top_57_i			794	cmp_bot_64_i:	BNE	\$9 \$0
743		XORI	\$11 1		cmp_top_63_i		
744	f_top_57_i:	BEQ	\$10 \$0	795		XORI	\$10 1
	f_bot_58_i			796	cmp_top_63_i:	BNE	\$9 \$0
745	cmp_bot_56_i:	BEQ	\$9 \$0		cmp_bot_64_i		
	cmp_top_55_i			797		ADD	\$8 \$3
746		XORI	\$10 1	798		ADDI	\$8 2
747	cmp_top_55_i:	BEQ	\$9 \$0	799		EXCH	\$9 \$8
	cmp_bot_56_i			800		ADDI	\$8 -2
748		ADD	\$8 \$3	801		SUB	\$8 \$3
749		ADDI	\$8 5	802	test_59:	BEQ	\$7 \$0
750		EXCH	\$9 \$8		test_false_61		
751		ADDI	\$8 -5	803		XORI	\$7 1
752		SUB	\$8 \$3	804		ADD	\$8 \$3
753	l_append_7_bot:	BRA	l_append_7_top	805		ADDI	\$8 2
754	l_appendCell_1_top:	BRA		806		EXCH	\$9 \$8
	l_appendCell_1_bot			807		ADDI	\$8 -2
755		ADDI	\$1 1	808		SUB	\$8 \$3
756		EXCH	\$2 \$1	809		EXCH	\$10 \$6
757		EXCH	\$6 \$1	810	swap_69:	XOR	\$9 \$10
758		ADDI	\$1 -1	811		XOR	\$10 \$9
759		EXCH	\$3 \$1	812		XOR	\$9 \$10
760		ADDI	\$1 -1	813		EXCH	\$10 \$6
761	l_appendCell_1:	SWAPBR	\$2	814		ADD	\$8 \$3
762		NEG	\$2	815		ADDI	\$8 2
763		ADDI	\$1 1	816		EXCH	\$9 \$8
764		EXCH	\$3 \$1	817		ADDI	\$8 -2
765		ADDI	\$1 1	818		SUB	\$8 \$3
766		EXCH	\$6 \$1	819		XORI	\$7 1
767		EXCH	\$2 \$1	820	assert_true_60:	BRA	assert_62
768		ADDI	\$1 -1	821	test_false_61:	BRA	test_59
769		ADD	\$8 \$3	822	assert_62:	BNE	\$7 \$0
770		ADDI	\$8 2		assert_true_60		
771		EXCH	\$9 \$8	823		ADD	\$8 \$3
772		ADDI	\$8 -2	824		ADDI	\$8 2
773		SUB	\$8 \$3	825		EXCH	\$9 \$8
774	cmp_top_63:	BNE	\$9 \$0	826		ADDI	\$8 -2
	cmp_bot_64			827		SUB	\$8 \$3

828	cmp_top_70:	BEQ	\$9 \$0	874		ADD	\$8 \$3
	cmp_bot_71			875		ADDI	\$8 2
829		XORI	\$10 1	876		EXCH	\$9 \$8
830	cmp_bot_71:	BEQ	\$9 \$0	877		ADDI	\$8 -2
	cmp_top_70			878		SUB	\$8 \$3
831		EXCH	\$11 \$6	879	test_76:	BEQ	\$7 \$0
832	cmp_top_72:	BNE	\$11 \$0		test_false_78		
	cmp_bot_73			880		XORI	\$7 1
833		XORI	\$12 1	881		ADD	\$8 \$3
834	cmp_bot_73:	BNE	\$11 \$0	882		ADDI	\$8 2
	cmp_top_72			883		EXCH	\$9 \$8
835		ANDX	\$13 \$10 \$12	884		ADDI	\$8 -2
836	f_top_74:	BEQ	\$13 \$0	885		SUB	\$8 \$3
	f_bot_75			886		XOR	\$10 \$9
837		XORI	\$14 1	887	loadMetAdd_84:	EXCH	\$11 \$10
838	f_bot_75:	BEQ	\$13 \$0	888		ADDI	\$11 5
	f_top_74			889		EXCH	\$12 \$11
839		XOR	\$7 \$14	890		XOR	\$13 \$12
840	f_bot_75_i:	BEQ	\$13 \$0	891		EXCH	\$12 \$11
	f_top_74_i			892		ADDI	\$11 -5
841		XORI	\$14 1	893		EXCH	\$11 \$10
842	f_top_74_i:	BEQ	\$13 \$0	894		ADD	\$8 \$3
	f_bot_75_i			895		ADDI	\$8 2
843		ANDX	\$13 \$10 \$12	896		EXCH	\$9 \$8
844	cmp_bot_73_i:	BNE	\$11 \$0	897		ADDI	\$8 -2
	cmp_top_72_i			898		SUB	\$8 \$3
845		XORI	\$12 1	899		EXCH	\$3 \$1
846	cmp_top_72_i:	BNE	\$11 \$0	900		ADDI	\$1 -1
	cmp_bot_73_i			901		EXCH	\$6 \$1
847		EXCH	\$11 \$6	902		ADDI	\$1 -1
848	cmp_bot_71_i:	BEQ	\$9 \$0	903		EXCH	\$10 \$1
	cmp_top_70_i			904		ADDI	\$1 -1
849		XORI	\$10 1	905		ADDI	\$13 -904
850	cmp_top_70_i:	BEQ	\$9 \$0	906	l_jmp_85:	SWAPBR	\$13
	cmp_bot_71_i			907		NEG	\$13
851		ADD	\$8 \$3	908		ADDI	\$13 904
852		ADDI	\$8 2	909		ADDI	\$1 1
853		EXCH	\$9 \$8	910		EXCH	\$10 \$1
854		ADDI	\$8 -2	911		ADDI	\$1 1
855		SUB	\$8 \$3	912		EXCH	\$6 \$1
856		ADD	\$8 \$3	913		ADDI	\$1 1
857		ADDI	\$8 2	914		EXCH	\$3 \$1
858		EXCH	\$9 \$8	915		ADD	\$8 \$3
859		ADDI	\$8 -2	916		ADDI	\$8 2
860		SUB	\$8 \$3	917		EXCH	\$9 \$8
861	cmp_top_80:	BEQ	\$9 \$0	918		ADDI	\$8 -2
	cmp_bot_81			919		SUB	\$8 \$3
862		XORI	\$10 1	920		EXCH	\$11 \$10
863	cmp_bot_81:	BEQ	\$9 \$0	921		ADDI	\$11 5
	cmp_top_80			922		EXCH	\$12 \$11
864	f_top_82:	BEQ	\$10 \$0	923		XOR	\$13 \$12
	f_bot_83			924		EXCH	\$12 \$11
865		XORI	\$11 1	925		ADDI	\$11 -5
866	f_bot_83:	BEQ	\$10 \$0	926	loadMetAdd_84_i:	EXCH	\$11 \$10
	f_top_82			927		XOR	\$10 \$9
867		XOR	\$7 \$11	928		ADD	\$8 \$3
868	f_bot_83_i:	BEQ	\$10 \$0	929		ADDI	\$8 2
	f_top_82_i			930		EXCH	\$9 \$8
869		XORI	\$11 1	931		ADDI	\$8 -2
870	f_top_82_i:	BEQ	\$10 \$0	932		SUB	\$8 \$3
	f_bot_83_i			933		XORI	\$7 1
871	cmp_bot_81_i:	BEQ	\$9 \$0	934	assert_true_77:	BRA	assert_79
	cmp_top_80_i			935	test_false_78:	BRA	test_76
872		XORI	\$10 1	936	assert_79:	BNE	\$7 \$0
873	cmp_top_80_i:	BEQ	\$9 \$0		assert_true_77		
	cmp_bot_81_i			937		ADD	\$8 \$3

938		ADDI	\$8 2	995		ADDI	\$1 1
939		EXCH	\$9 \$8	996		EXCH	\$8 \$1
940		ADDI	\$8 -2	997	obj_con_90_i:	ADDI	\$8 -4
941		SUB	\$8 \$3	998		ADDI	\$1 1
942	cmp_top_86:	BEQ	\$9 \$0	999		EXCH	\$3 \$1
	cmp_bot_87			1000		ADD	\$6 \$3
943		XORI	\$10 1	1001		ADDI	\$6 2
944	cmp_bot_87:	BEQ	\$9 \$0	1002		XORI	\$8 4
	cmp_top_86			1003		EXCH	\$8 \$7
945	f_top_88:	BEQ	\$10 \$0	1004		ADDI	\$7 1
	f_bot_89			1005		XORI	\$8 1
946		XORI	\$11 1	1006		EXCH	\$8 \$7
947	f_bot_89:	BEQ	\$10 \$0	1007	obj_con_90_bot:	ADDI	\$7 -1
	f_top_88			1008		EXCH	\$7 \$6
948		XOR	\$7 \$11	1009		ADDI	\$6 -2
949	f_bot_89_i:	BEQ	\$10 \$0	1010		SUB	\$6 \$3
	f_top_88_i			1011		ADD	\$6 \$3
950		XORI	\$11 1	1012		ADDI	\$6 3
951	f_top_88_i:	BEQ	\$10 \$0	1013		EXCH	\$7 \$6
	f_bot_89_i			1014		ADDI	\$6 -3
952	cmp_bot_87_i:	BEQ	\$9 \$0	1015		SUB	\$6 \$3
	cmp_top_86_i			1016		XORI	\$8 10
953		XORI	\$10 1	1017		ADD	\$7 \$8
954	cmp_top_86_i:	BEQ	\$9 \$0	1018		XORI	\$8 10
	cmp_bot_87_i			1019		ADD	\$6 \$3
955		ADD	\$8 \$3	1020		ADDI	\$6 3
956		ADDI	\$8 2	1021		EXCH	\$7 \$6
957		EXCH	\$9 \$8	1022		ADDI	\$6 -3
958		ADDI	\$8 -2	1023		SUB	\$6 \$3
959		SUB	\$8 \$3	1024	localBlock_113:	XOR	\$6 \$1
960		ADD	\$7 \$3	1025		XOR	\$7 \$0
961		ADDI	\$7 3	1026		EXCH	\$7 \$1
962		EXCH	\$8 \$7	1027		ADDI	\$1 -1
963		ADDI	\$7 -3	1028		XORI	\$7 1
964		SUB	\$7 \$3	1029	entry_91:	BEQ	\$7 \$0
965		XORI	\$9 1		assert_93		
966		ADD	\$8 \$9	1030		EXCH	\$8 \$6
967		XORI	\$9 1	1031	cmp_top_95:	BNE	\$8 \$0
968		ADD	\$7 \$3		cmp_bot_96		
969		ADDI	\$7 3	1032		XORI	\$9 1
970		EXCH	\$8 \$7	1033	cmp_bot_96:	BNE	\$8 \$0
971		ADDI	\$7 -3		cmp_top_95		
972		SUB	\$7 \$3	1034	f_top_97:	BEQ	\$9 \$0 f_bot_98
973	l_appendCell_1_bot:	BRA		1035		XORI	\$10 1
	l_appendCell_1_top			1036	f_bot_98:	BEQ	\$9 \$0 f_top_97
974	l_main_0_top:	BRA	l_main_0_bot	1037		XOR	\$7 \$10
975		ADDI	\$1 1	1038	f_bot_98_i:	BEQ	\$9 \$0
976		EXCH	\$2 \$1		f_top_97_i		
977		EXCH	\$3 \$1	1039		XORI	\$10 1
978		ADDI	\$1 -1	1040	f_top_97_i:	BEQ	\$9 \$0
979	l_main_0:	SWAPBR	\$2		f_bot_98_i		
980		NEG	\$2	1041	cmp_bot_96_i:	BNE	\$8 \$0
981		ADDI	\$1 1		cmp_top_95_i		
982		EXCH	\$3 \$1	1042		XORI	\$9 1
983		EXCH	\$2 \$1	1043	cmp_top_95_i:	BNE	\$8 \$0
984		ADDI	\$1 -1		cmp_bot_96_i		
985		EXCH	\$3 \$1	1044		EXCH	\$8 \$6
986		ADDI	\$1 -1	1045		EXCH	\$8 \$6
987	obj_con_90:	ADDI	\$8 4	1046		ADD	\$9 \$3
988		EXCH	\$8 \$1	1047		ADDI	\$9 3
989		ADDI	\$1 -1	1048		EXCH	\$10 \$9
990		EXCH	\$7 \$1	1049		ADDI	\$9 -3
991		ADDI	\$1 -1	1050		SUB	\$9 \$3
992		BRA	l_malloc	1051	cmp_top_109:	BNE	\$8 \$10
993		ADDI	\$1 1		cmp_bot_110		
994		EXCH	\$7 \$1	1052		XORI	\$11 1

1053	cmp_bot_110:	BNE	\$8 \$10	1112		ADDI	\$11 1
	cmp_top_109			1113		EXCH	\$12 \$11
1054	f_top_111:	BEQ	\$11 \$0	1114		ADDI	\$12 1
	f_bot_112			1115		EXCH	\$12 \$11
1055		XORI	\$12 1	1116		ADDI	\$11 -1
1056	f_bot_112:	BEQ	\$11 \$0	1117		EXCH	\$11 \$8
	f_top_111			1118		EXCH	\$10 \$9
1057		XOR	\$7 \$12	1119		EXCH	\$10 \$8
1058	f_bot_112_i:	BEQ	\$11 \$0	1120		XOR	\$11 \$10
	f_top_111_i			1121	loadMetAdd_101:	EXCH	\$12 \$11
1059		XORI	\$12 1	1122		ADDI	\$12 4
1060	f_top_111_i:	BEQ	\$11 \$0	1123		EXCH	\$13 \$12
	f_bot_112_i			1124		XOR	\$14 \$13
1061	cmp_bot_110_i:	BNE	\$8 \$10	1125		EXCH	\$13 \$12
	cmp_top_109_i			1126		ADDI	\$12 -4
1062		XORI	\$11 1	1127		EXCH	\$12 \$11
1063	cmp_top_109_i:	BNE	\$8 \$10	1128		EXCH	\$10 \$8
	cmp_bot_110_i			1129		EXCH	\$3 \$1
1064		ADD	\$9 \$3	1130		ADDI	\$1 -1
1065		ADDI	\$9 3	1131		EXCH	\$8 \$1
1066		EXCH	\$10 \$9	1132		ADDI	\$1 -1
1067		ADDI	\$9 -3	1133		EXCH	\$6 \$1
1068		SUB	\$9 \$3	1134		ADDI	\$1 -1
1069		EXCH	\$8 \$6	1135		EXCH	\$9 \$1
1070	test_92:	BNE	\$7 \$0 exit_94	1136		ADDI	\$1 -1
1071	localBlock_108:	XOR	\$8 \$1	1137		EXCH	\$11 \$1
1072		XOR	\$9 \$0	1138		ADDI	\$1 -1
1073		EXCH	\$9 \$1	1139		ADDI	\$14 -1138
1074		ADDI	\$1 -1	1140	l_jump_102:	SWAPBR	\$14
1075		EXCH	\$3 \$1	1141		NEG	\$14
1076		ADDI	\$1 -1	1142		ADDI	\$14 1138
1077		EXCH	\$8 \$1	1143		ADDI	\$1 1
1078		ADDI	\$1 -1	1144		EXCH	\$11 \$1
1079		EXCH	\$6 \$1	1145		ADDI	\$1 1
1080		ADDI	\$1 -1	1146		EXCH	\$9 \$1
1081	obj_con_99:	ADDI	\$10 8	1147		ADDI	\$1 1
1082		EXCH	\$10 \$1	1148		EXCH	\$6 \$1
1083		ADDI	\$1 -1	1149		ADDI	\$1 1
1084		EXCH	\$9 \$1	1150		EXCH	\$8 \$1
1085		ADDI	\$1 -1	1151		ADDI	\$1 1
1086		BRA	l_malloc	1152		EXCH	\$3 \$1
1087		ADDI	\$1 1	1153		EXCH	\$10 \$8
1088		EXCH	\$9 \$1	1154		EXCH	\$12 \$11
1089		ADDI	\$1 1	1155		ADDI	\$12 4
1090		EXCH	\$10 \$1	1156		EXCH	\$13 \$12
1091	obj_con_99_i:	ADDI	\$10 -8	1157		XOR	\$14 \$13
1092		ADDI	\$1 1	1158		EXCH	\$13 \$12
1093		EXCH	\$6 \$1	1159		ADDI	\$12 -4
1094		ADDI	\$1 1	1160	loadMetAdd_101_i:	EXCH	\$12 \$11
1095		EXCH	\$8 \$1	1161		XOR	\$11 \$10
1096		ADDI	\$1 1	1162		EXCH	\$10 \$8
1097		EXCH	\$3 \$1	1163		ADDI	\$1 1
1098		XORI	\$10 5	1164		EXCH	\$10 \$1
1099		EXCH	\$10 \$9	1165		XOR	\$10 \$0
1100		ADDI	\$9 1	1166	localBlock_103_i:	XOR	\$9 \$1
1101		XORI	\$10 1	1167		EXCH	\$9 \$8
1102		EXCH	\$10 \$9	1168		XOR	\$10 \$9
1103	obj_con_99_bot:	ADDI	\$9 -1	1169	loadMetAdd_104:	EXCH	\$11 \$10
1104		EXCH	\$9 \$8	1170		ADDI	\$11 0
1105	localBlock_103:	XOR	\$9 \$1	1171		EXCH	\$12 \$11
1106		XOR	\$10 \$0	1172		XOR	\$13 \$12
1107		EXCH	\$10 \$1	1173		EXCH	\$12 \$11
1108		ADDI	\$1 -1	1174		ADDI	\$11 0
1109		EXCH	\$10 \$9	1175		EXCH	\$11 \$10
1110		EXCH	\$11 \$8	1176		EXCH	\$9 \$8
1111	copy_100:	XOR	\$10 \$11	1177		EXCH	\$3 \$1

1178		ADDI	\$1 -1	1244		EXCH	\$3 \$1
1179		EXCH	\$8 \$1	1245		ADD	\$9 \$3
1180		ADDI	\$1 -1	1246		ADDI	\$9 2
1181		EXCH	\$6 \$1	1247		EXCH	\$10 \$9
1182		ADDI	\$1 -1	1248		ADDI	\$9 -2
1183		EXCH	\$10 \$1	1249		SUB	\$9 \$3
1184		ADDI	\$1 -1	1250		EXCH	\$12 \$11
1185		ADDI	\$13 -1184	1251		ADDI	\$12 0
1186	l_jump_105:	SWAPBR	\$13	1252		EXCH	\$13 \$12
1187		NEG	\$13	1253		XOR	\$14 \$13
1188		ADDI	\$13 1184	1254		EXCH	\$13 \$12
1189		ADDI	\$1 1	1255		ADDI	\$12 0
1190		EXCH	\$10 \$1	1256	loadMetAdd_106_i:	EXCH	\$12 \$11
1191		ADDI	\$1 1	1257		XOR	\$11 \$10
1192		EXCH	\$6 \$1	1258		ADD	\$9 \$3
1193		ADDI	\$1 1	1259		ADDI	\$9 2
1194		EXCH	\$8 \$1	1260		EXCH	\$10 \$9
1195		ADDI	\$1 1	1261		ADDI	\$9 -2
1196		EXCH	\$3 \$1	1262		SUB	\$9 \$3
1197		EXCH	\$9 \$8	1263		ADDI	\$1 1
1198		EXCH	\$11 \$10	1264		EXCH	\$9 \$1
1199		ADDI	\$11 0	1265		XOR	\$9 \$0
1200		EXCH	\$12 \$11	1266	localBlock_108_i:	XOR	\$8 \$1
1201		XOR	\$13 \$12	1267		EXCH	\$8 \$6
1202		EXCH	\$12 \$11	1268		XORI	\$9 1
1203		ADDI	\$11 0	1269		ADD	\$8 \$9
1204	loadMetAdd_104_i:	EXCH	\$11 \$10	1270		XORI	\$9 1
1205		XOR	\$10 \$9	1271		EXCH	\$8 \$6
1206		EXCH	\$9 \$8	1272	assert_93:	BRA	entry_91
1207		ADD	\$9 \$3	1273	exit_94:	BRA	test_92
1208		ADDI	\$9 2	1274		XORI	\$7 1
1209		EXCH	\$10 \$9	1275		ADD	\$7 \$3
1210		ADDI	\$9 -2	1276		ADDI	\$7 3
1211		SUB	\$9 \$3	1277		EXCH	\$8 \$7
1212		XOR	\$11 \$10	1278		ADDI	\$7 -3
1213	loadMetAdd_106:	EXCH	\$12 \$11	1279		SUB	\$7 \$3
1214		ADDI	\$12 0	1280		ADDI	\$1 1
1215		EXCH	\$13 \$12	1281		EXCH	\$9 \$1
1216		XOR	\$14 \$13	1282		XOR	\$9 \$8
1217		EXCH	\$13 \$12	1283	localBlock_113_i:	XOR	\$6 \$1
1218		ADDI	\$12 0	1284		ADD	\$7 \$3
1219		EXCH	\$12 \$11	1285		ADDI	\$7 3
1220		ADD	\$9 \$3	1286		EXCH	\$8 \$7
1221		ADDI	\$9 2	1287		ADDI	\$7 -3
1222		EXCH	\$10 \$9	1288		SUB	\$7 \$3
1223		ADDI	\$9 -2	1289	l_main_0_bot:	BRA	l_main_0_top
1224		SUB	\$9 \$3	1290	start:	BRA	top
1225		EXCH	\$3 \$1	1291		START	
1226		ADDI	\$1 -1	1292		ADDI	\$4 1338
1227		EXCH	\$6 \$1	1293		XOR	\$5 \$4
1228		ADDI	\$1 -1	1294		ADDI	\$5 10
1229		EXCH	\$8 \$1	1295		XOR	\$7 \$5
1230		ADDI	\$1 -1	1296		ADDI	\$4 10
1231		EXCH	\$11 \$1	1297		ADDI	\$4 -1
1232		ADDI	\$1 -1	1298		EXCH	\$7 \$4
1233		ADDI	\$14 -1232	1299		ADDI	\$4 1
1234	l_jump_107:	SWAPBR	\$14	1300		ADDI	\$4 -10
1235		NEG	\$14	1301		XOR	\$1 \$5
1236		ADDI	\$14 1232	1302		ADDI	\$1 2048
1237		ADDI	\$1 1	1303		ADDI	\$1 -4
1238		EXCH	\$11 \$1	1304		XOR	\$3 \$1
1239		ADDI	\$1 1	1305		XORI	\$6 3
1240		EXCH	\$8 \$1	1306		EXCH	\$6 \$3
1241		ADDI	\$1 1	1307		ADDI	\$1 -1
1242		EXCH	\$6 \$1	1308		EXCH	\$3 \$1
1243		ADDI	\$1 1	1309		ADDI	\$1 -1

1310	BRA	l_main_0	1325	EXCH	\$6 \$7
1311	ADDI	\$1 1	1326	XORI	\$7 2
1312	EXCH	\$3 \$1	1327	ADDI	\$3 -2
1313	ADDI	\$3 1	1328	ADDI	\$3 -1
1314	ADDI	\$3 1	1329	ADDI	\$1 1
1315	EXCH	\$6 \$3	1330	EXCH	\$6 \$3
1316	XORI	\$7 1	1331	XORI	\$6 3
1317	EXCH	\$6 \$7	1332	XOR	\$3 \$1
1318	XORI	\$7 1	1333	ADDI	\$1 4
1319	ADDI	\$3 -1	1334	ADDI	\$1 -2048
1320	ADDI	\$3 -1	1335	XOR	\$1 \$5
1321	ADDI	\$3 1	1336	ADDI	\$5 -10
1322	ADDI	\$3 2	1337	XOR	\$5 \$4
1323	EXCH	\$6 \$3	1338	ADDI	\$4 -1338
1324	XORI	\$7 2	1339	FINISH	

finish:

RTM.rplpp

```
1 class Cell
2     Cell self
3     Cell right
4     Cell left
5     int data
6
7     method getLeft(Cell cell)
8         right <=> cell
9
10    method getRight(Cell cell)
11        left <=> cell
12
13    method getSelf(Cell cell)
14        self <=> cell
15
16    method getSymbol(int symbol)
17        symbol <=> data
18
19 class RTM
20     Cell tapeHead
21     int[] q1
22     int[] q2
23     int[] s1
24     int[] s2
25     int SLASH
26     int LEFT
27     int RIGHT
28     int BLANK
29     int state
30     int Qs
31     int Qf
32     int symbol
33     int PC_MAX
34     int pc
35
36    method initLiterals()
37        // Initialize string literals
38        SLASH += 9999
39        LEFT += 9998
40        RIGHT += 9997
41        BLANK += 9996
42
43        // Set max program counter
44        PC_MAX += 7
45
46    method initRules()
47        // Initialize transition rule arrays
48        new int[8] q1
49        new int[8] q2
50        new int[8] s1
51        new int[8] s2
52
53        // Define transition rules for binary number incrementation
54        q1[0] += 1
55        s1[0] += BLANK
56        s2[0] += BLANK
57        q2[0] += 2
58
59        q1[1] += 2
60        s1[1] += SLASH
61        s2[1] += RIGHT
62        q2[1] += 3
63
```



```

64         q1[2] += 3
65         s1[2] += 0
66         s2[2] += 1
67         q2[2] += 4
68
69         q1[3] += 3
70         s1[3] += 1
71         s2[3] += 0
72         q2[3] += 2
73
74         q1[4] += 3
75         s1[4] += BLANK
76         s2[4] += BLANK
77         q2[4] += 4
78
79         q1[5] += 4
80         s1[5] += SLASH
81         s2[5] += LEFT
82         q2[5] += 5
83
84         q1[6] += 5
85         s1[6] += 0
86         s2[6] += 0
87         q2[6] += 4
88
89         q1[7] += 5
90         s1[7] += BLANK
91         s2[7] += BLANK
92         q2[7] += 6
93
94     method initTape()
95         local Cell cell0 = nil
96         local Cell cell1 = nil
97         local Cell cell2 = nil
98         local Cell cell3 = nil
99         local Cell cell4 = nil
100
101         // Init cells
102         new Cell cell0
103         new Cell cell1
104         new Cell cell2
105         new Cell cell3
106         new Cell cell4
107
108         // Write 1 1 0 1 on tape
109         symbol += BLANK
110         uncall cell0::getSymbol(symbol)
111         symbol += 1
112         uncall cell1::getSymbol(symbol)
113         symbol += 1
114         uncall cell2::getSymbol(symbol)
115         symbol += 1
116         uncall cell4::getSymbol(symbol)
117
118         // Set tape head
119         tapeHead <=> cell0
120
121         // Set self pointers
122         copy Cell tapeHead cell0
123         uncall tapeHead::getSelf(cell0)
124         copy Cell cell1 cell0
125         uncall cell1::getSelf(cell0)
126         copy Cell cell2 cell0
127         uncall cell2::getSelf(cell0)
128         copy Cell cell3 cell0
129         uncall cell3::getSelf(cell0)

```

```

130     copy Cell cell4 cell0
131     uncall cell4::getSelf(cell0)
132
133     // Link cell 3 and 4
134     copy Cell cell3 cell0
135     uncall cell4::getLeft(cell0)
136     uncall cell3::getRight(cell4)
137
138     // Link cell 2 and 3
139     copy Cell cell2 cell0
140     uncall cell3::getLeft(cell0)
141     uncall cell2::getRight(cell3)
142
143     // Link cell1 and cell 2
144     copy Cell cell1 cell0
145     uncall cell2::getLeft(cell0)
146     uncall cell1::getRight(cell2)
147
148     // Link tapeHead and cell 1
149     copy Cell tapeHead cell0
150     uncall cell1::getLeft(cell0)
151     uncall tapeHead::getRight(cell1)
152
153     delocal Cell cell4 = nil
154     delocal Cell cell3 = nil
155     delocal Cell cell2 = nil
156     delocal Cell cell1 = nil
157     delocal Cell cell0 = nil
158
159     method init()
160         // Prepare for simulation
161         call initLiterals()
162         call initRules()
163         call initTape()
164
165         // Init pc, start and finishing state
166         state += 1
167         Qs += 1
168         Qf += 6
169
170         // Start simulation
171         call simulate()
172
173     method simulate()
174         from state = Qs do
175             call tapeHead::getSymbol(symbol) // Fetch current symbol
176             call inst()
177             uncall tapeHead::getSymbol(symbol) // Zero-clear symbol
178             pc += 1 // Increment pc
179
180             if pc = PC_MAX then // Reset pc
181                 pc ^= PC_MAX
182             else skip
183             fi pc = 0
184         loop skip
185         until state = Qf
186
187     method inst()
188         if state = q1[pc] & symbol = s1[pc] then // Symbol rule:
189             state += q2[pc]-q1[pc] // set state to q2[pc]
190             symbol += s2[pc]-s1[pc] // set symbol to s2[pc]
191         else skip
192         fi state = q2[pc] & symbol = s2[pc]
193         if state = q1[pc] & s1[pc] = SLASH then // Move rule:
194             state += q2[pc]-q1[pc] // set state to q2[pc]
195             if s2[pc] = RIGHT then

```

```

196         call moveRight() // Move tape head right
197     else skip
198     fi s2[pc] = RIGHT
199     if s2[pc] = LEFT then
200         uncall moveRight() // Move tape head left
201     else skip
202     fi s2[pc] = LEFT
203 else skip
204 fi state = q2[pc] & s1[pc] = SLASH
205
206 method moveRight()
207     local Cell right = nil
208     local Cell tmp = nil
209     uncall tapeHead::getSymbol(symbol) // Put symbol back in current cell
210     call tapeHead::getRight(right) // Get right neighbour
211
212     if right = nil & symbol = BLANK then
213         symbol ^= BLANK // Zero clear symbol
214         new Cell right // Init new neighbour
215         copy Cell right tmp // Copy reference to self
216         uncall right::getSelf(tmp) // Store self reference
217         uncall right::getLeft(tapeHead) // Set tape head as left of new cell
218         right <=> tapeHead
219     else
220         call right::getLeft(tmp) // Get copy of tape head reference
221         uncopy Cell tmp tapeHead // Clear reference to tape head
222
223         if tapeHead = nil & symbol = BLANK then
224             call tmp::getSelf(tapeHead) // rev: set self pointer
225             uncopy Cell tmp tapeHead // rev: new self pointer
226             delete Cell tmp // rev: new left neighbour
227             symbol ^= BLANK
228         else skip // In reverse:
229         fi tmp = nil // Allocate new left if current is nil
230
231         uncall right::getLeft(tmp) // Put tape head reference back
232         tapeHead <=> right
233         call tapeHead::getRight(right) // Get right of new tape head
234         call tapeHead::getSymbol(symbol) // Get symbol of new tape head
235     fi right = nil
236
237     uncall tapeHead::getRight(right) // Set right neighbour
238     delocal Cell right = nil
239     delocal Cell tmp = nil
240
241 class Program
242     RTM bni
243
244     method main()
245         // This program contains a RTM implementing
246         // incrementation of a non-negative n-bit binary number by 1 (modulo 2n).
247         // The tape is initialized with | b | 1 | 0 | 0 | and after execution,
248         // the tape is left with | b | 0 | 0 | 1 | 1 |
249         new RTM bni
250         call bni::init()

```

RTM.pal

```

1  ;; pendulum pal file
2  top:          BRA    start          61
3  l_r_bni:      DATA  0              62  l_o_test:
4  l_Program_vt: DATA  6592           63      l_o_test_false
5  l_RTM_vt:     DATA  348            64
6              DATA  425            65
7              DATA  2181           66
8              DATA  3606           67
9              DATA  3677           68
10             DATA  3976           69
11             DATA  5727           70
12 l_Cell_vt:    DATA  226           71
13             DATA  257            72
14             DATA  288            73
15             DATA  319            74
16 l_malloc_top: BRA    l_malloc_bot  75
17 l_malloc:     SWAPBR $2            76
18             NEG     $2            77
19             ADDI    $9 2           78
20             XOR     $8 $0          79
21             ADDI    $1 1           80
22             EXCH    $6 $1          81
23             ADDI    $1 1           82
24             EXCH    $7 $1          83
25             EXCH    $2 $1          84
26             ADDI    $1 -1          85
27             BRA     l_malloc1      86
28             ADDI    $1 1           87
29             EXCH    $2 $1          88
30             EXCH    $7 $1          89
31             ADDI    $1 -1          90
32             EXCH    $6 $1          91
33             ADDI    $1 -1          92
34             XOR     $8 $0          93
35             ADDI    $9 -2          94
36 l_malloc_bot: BRA     l_malloc_top 95
37 l_malloc1_top: BRA    l_malloc1_bot 96
38             ADDI    $1 1           97
39             EXCH    $2 $1          98
40             SUB     $17 $8         99
41             XOR     $17 $4        100
42 l_malloc1:    SWAPBR $2            101
43             NEG     $2            102
44             EXCH    $2 $1          103
45             ADDI    $1 -1          104
46             XOR     $17 $4        105
47             ADD     $17 $8         106
48             EXCH    $19 $17       107
49             XOR     $18 $19       108
50             EXCH    $19 $17       109
51             XOR     $13 $9        110
52             SUB     $13 $7        111
53 cmp_top_12:   BGEZ    $13 cmp_bot_13 112
54             XORI    $14 1         113
55 cmp_bot_13:   BGEZ    $13 cmp_top_12 114
56             XOR     $10 $14       115
57 cmp_bot_13_i: BGEZ    $13         116
58             cmp_top_12_i          117  l_o_assert_true:
59 cmp_top_12_i: BGEZ    $13         118  l_o_test_false:
60             cmp_bot_13_i          119  cmp_top_16:
61                                     120  cmp_bot_17

```

121	cmp_bot_17:	BEQ	\$18 \$0	183		RR	\$9 1
	cmp_top_16			184		ADDI	\$8 -1
122		XOR	\$11 \$20	185		XOR	\$12 \$6
123	cmp_bot_17_i:	BEQ	\$18 \$0	186		EXCH	\$12 \$17
	cmp_top_16_i			187		ADD	\$6 \$9
124		XORI	\$20 1	188	l_i_assert:	BNE	\$11 \$0
125	cmp_top_16_i:	BEQ	\$18 \$0		l_i_assert_true		
	cmp_bot_17_i			189		EXCH	\$12 \$17
126	l_i_test:	BEQ	\$11 \$0	190		SUB	\$6 \$9
	l_i_test_false			191	cmp_top_18:	BEQ	\$6 \$12
127		XORI	\$11 1		cmp_bot_19		
128		ADD	\$6 \$18	192		XORI	\$21 1
129		SUB	\$18 \$6	193	cmp_bot_19:	BEQ	\$6 \$12
130		EXCH	\$12 \$6		cmp_top_18		
131		EXCH	\$12 \$17	194	cmp_top_20:	BNE	\$12 \$0
132		XOR	\$12 \$6		cmp_bot_21		
133		XORI	\$11 1	195		XORI	\$22 1
134	l_i_assert_true:	BRA	l_i_assert	196	cmp_bot_21:	BNE	\$12 \$0
135	l_i_test_false:	BRA	l_i_test		cmp_top_20		
136		ADDI	\$8 1	197		ORX	\$23 \$21 \$22
137		RL	\$9 1	198		XOR	\$11 \$23
138		EXCH	\$10 \$1	199		ORX	\$23 \$21 \$22
139		ADDI	\$1 -1	200	cmp_bot_21_i:	BNE	\$12 \$0
140		EXCH	\$11 \$1		cmp_top_20_i		
141		ADDI	\$1 -1	201		XORI	\$22 1
142		EXCH	\$12 \$1	202	cmp_top_20_i:	BNE	\$12 \$0
143		ADDI	\$1 -1		cmp_bot_21_i		
144		EXCH	\$14 \$1	203	cmp_bot_19_i:	BEQ	\$6 \$12
145		ADDI	\$1 -1		cmp_top_18_i		
146		EXCH	\$16 \$1	204		XORI	\$21 1
147		ADDI	\$1 -1	205	cmp_top_18_i:	BEQ	\$6 \$12
148		EXCH	\$17 \$1		cmp_bot_19_i		
149		ADDI	\$1 -1	206		ADD	\$6 \$9
150		EXCH	\$18 \$1	207		EXCH	\$12 \$17
151		ADDI	\$1 -1	208	l_o_assert:	BNE	\$10 \$0
152		EXCH	\$20 \$1		l_o_assert_true		
153		ADDI	\$1 -1	209		XOR	\$15 \$9
154		EXCH	\$21 \$1	210		SUB	\$15 \$7
155		ADDI	\$1 -1	211	cmp_top_14:	BGEZ	\$15 cmp_bot_15
156		EXCH	\$22 \$1	212		XORI	\$16 1
157		ADDI	\$1 -1	213	cmp_bot_15:	BGEZ	\$15 cmp_top_14
158		EXCH	\$23 \$1	214		XOR	\$10 \$16
159		ADDI	\$1 -1	215	cmp_bot_15_i:	BGEZ	\$15
160		BRA	l_malloc1		cmp_top_14_i		
161		ADDI	\$1 1	216		XORI	\$16 1
162		EXCH	\$23 \$1	217	cmp_top_14_i:	BGEZ	\$15
163		ADDI	\$1 1		cmp_bot_15_i		
164		EXCH	\$22 \$1	218		ADD	\$15 \$7
165		ADDI	\$1 1	219		XOR	\$15 \$9
166		EXCH	\$21 \$1	220	l_malloc1_bot:	BRA	l_malloc1_top
167		ADDI	\$1 1	221	l_getLeft_8_top:	BRA	
168		EXCH	\$20 \$1		l_getLeft_8_bot		
169		ADDI	\$1 1	222		ADDI	\$1 1
170		EXCH	\$18 \$1	223		EXCH	\$2 \$1
171		ADDI	\$1 1	224		EXCH	\$6 \$1
172		EXCH	\$17 \$1	225		ADDI	\$1 -1
173		ADDI	\$1 1	226		EXCH	\$3 \$1
174		EXCH	\$16 \$1	227		ADDI	\$1 -1
175		ADDI	\$1 1	228	l_getLeft_8:	SWAPBR	\$2
176		EXCH	\$14 \$1	229		NEG	\$2
177		ADDI	\$1 1	230		ADDI	\$1 1
178		EXCH	\$12 \$1	231		EXCH	\$3 \$1
179		ADDI	\$1 1	232		ADDI	\$1 1
180		EXCH	\$11 \$1	233		EXCH	\$6 \$1
181		ADDI	\$1 1	234		EXCH	\$2 \$1
182		EXCH	\$10 \$1	235		ADDI	\$1 -1

236		ADD	\$7 \$3	298		ADD	\$7 \$3
237		ADDI	\$7 3	299		ADDI	\$7 2
238		EXCH	\$8 \$7	300		EXCH	\$8 \$7
239		ADDI	\$7 -3	301		ADDI	\$7 -2
240		SUB	\$7 \$3	302		SUB	\$7 \$3
241		EXCH	\$9 \$6	303		EXCH	\$9 \$6
242	swap_22:	XOR	\$8 \$9	304	swap_24:	XOR	\$8 \$9
243		XOR	\$9 \$8	305		XOR	\$9 \$8
244		XOR	\$8 \$9	306		XOR	\$8 \$9
245		EXCH	\$9 \$6	307		EXCH	\$9 \$6
246		ADD	\$7 \$3	308		ADD	\$7 \$3
247		ADDI	\$7 3	309		ADDI	\$7 2
248		EXCH	\$8 \$7	310		EXCH	\$8 \$7
249		ADDI	\$7 -3	311		ADDI	\$7 -2
250		SUB	\$7 \$3	312		SUB	\$7 \$3
251	l_getLeft_8_bot:	BRA		313	l_getSelf_10_bot:	BRA	
	l_getLeft_8_top				l_getSelf_10_top		
252	l_getRight_9_top:	BRA		314	l_getSymbol_11_top:	BRA	
	l_getRight_9_bot				l_getSymbol_11_bot		
253		ADDI	\$1 1	315		ADDI	\$1 1
254		EXCH	\$2 \$1	316		EXCH	\$2 \$1
255		EXCH	\$6 \$1	317		EXCH	\$6 \$1
256		ADDI	\$1 -1	318		ADDI	\$1 -1
257		EXCH	\$3 \$1	319		EXCH	\$3 \$1
258		ADDI	\$1 -1	320		ADDI	\$1 -1
259	l_getRight_9:	SWAPBR	\$2	321	l_getSymbol_11:	SWAPBR	\$2
260		NEG	\$2	322		NEG	\$2
261		ADDI	\$1 1	323		ADDI	\$1 1
262		EXCH	\$3 \$1	324		EXCH	\$3 \$1
263		ADDI	\$1 1	325		ADDI	\$1 1
264		EXCH	\$6 \$1	326		EXCH	\$6 \$1
265		EXCH	\$2 \$1	327		EXCH	\$2 \$1
266		ADDI	\$1 -1	328		ADDI	\$1 -1
267		ADD	\$7 \$3	329		EXCH	\$7 \$6
268		ADDI	\$7 4	330		ADD	\$8 \$3
269		EXCH	\$8 \$7	331		ADDI	\$8 5
270		ADDI	\$7 -4	332		EXCH	\$9 \$8
271		SUB	\$7 \$3	333		ADDI	\$8 -5
272		EXCH	\$9 \$6	334		SUB	\$8 \$3
273	swap_23:	XOR	\$8 \$9	335	swap_25:	XOR	\$7 \$9
274		XOR	\$9 \$8	336		XOR	\$9 \$7
275		XOR	\$8 \$9	337		XOR	\$7 \$9
276		EXCH	\$9 \$6	338		ADD	\$8 \$3
277		ADD	\$7 \$3	339		ADDI	\$8 5
278		ADDI	\$7 4	340		EXCH	\$9 \$8
279		EXCH	\$8 \$7	341		ADDI	\$8 -5
280		ADDI	\$7 -4	342		SUB	\$8 \$3
281		SUB	\$7 \$3	343		EXCH	\$7 \$6
282	l_getRight_9_bot:	BRA		344	l_getSymbol_11_bot:	BRA	
	l_getRight_9_top				l_getSymbol_11_top		
283	l_getSelf_10_top:	BRA		345	l_initLiterals_1_top:	BRA	
	l_getSelf_10_bot				l_initLiterals_1_bot		
284		ADDI	\$1 1	346		ADDI	\$1 1
285		EXCH	\$2 \$1	347		EXCH	\$2 \$1
286		EXCH	\$6 \$1	348		EXCH	\$3 \$1
287		ADDI	\$1 -1	349		ADDI	\$1 -1
288		EXCH	\$3 \$1	350	l_initLiterals_1:	SWAPBR	\$2
289		ADDI	\$1 -1	351		NEG	\$2
290	l_getSelf_10:	SWAPBR	\$2	352		ADDI	\$1 1
291		NEG	\$2	353		EXCH	\$3 \$1
292		ADDI	\$1 1	354		EXCH	\$2 \$1
293		EXCH	\$3 \$1	355		ADDI	\$1 -1
294		ADDI	\$1 1	356		ADD	\$6 \$3
295		EXCH	\$6 \$1	357		ADDI	\$6 7
296		EXCH	\$2 \$1	358		EXCH	\$7 \$6
297		ADDI	\$1 -1	359		ADDI	\$6 -7

360		SUB	\$6 \$3	424		EXCH	\$2 \$1
361		XORI	\$8 9999	425		EXCH	\$3 \$1
362		ADD	\$7 \$8	426		ADDI	\$1 -1
363		XORI	\$8 9999	427	l_initRules_2:	SWAPBR	\$2
364		ADD	\$6 \$3	428		NEG	\$2
365		ADDI	\$6 7	429		ADDI	\$1 1
366		EXCH	\$7 \$6	430		EXCH	\$3 \$1
367		ADDI	\$6 -7	431		EXCH	\$2 \$1
368		SUB	\$6 \$3	432		ADDI	\$1 -1
369		ADD	\$6 \$3	433		XORI	\$7 8
370		ADDI	\$6 8	434	arr_con_26:	ADDI	\$9 2
371		EXCH	\$7 \$6	435		ADD	\$9 \$7
372		ADDI	\$6 -8	436		XORI	\$7 8
373		SUB	\$6 \$3	437		EXCH	\$3 \$1
374		XORI	\$8 9998	438		ADDI	\$1 -1
375		ADD	\$7 \$8	439		EXCH	\$9 \$1
376		XORI	\$8 9998	440		ADDI	\$1 -1
377		ADD	\$6 \$3	441		EXCH	\$8 \$1
378		ADDI	\$6 8	442		ADDI	\$1 -1
379		EXCH	\$7 \$6	443		BRA	l_malloc
380		ADDI	\$6 -8	444		ADDI	\$1 1
381		SUB	\$6 \$3	445		EXCH	\$8 \$1
382		ADD	\$6 \$3	446		ADDI	\$1 1
383		ADDI	\$6 9	447		EXCH	\$9 \$1
384		EXCH	\$7 \$6	448		ADDI	\$1 1
385		ADDI	\$6 -9	449		EXCH	\$3 \$1
386		SUB	\$6 \$3	450		XORI	\$7 8
387		XORI	\$8 9997	451		SUB	\$9 \$7
388		ADD	\$7 \$8	452	arr_con_26_i:	ADDI	\$9 -2
389		XORI	\$8 9997	453		XORI	\$7 8
390		ADD	\$6 \$3	454		ADD	\$6 \$3
391		ADDI	\$6 9	455		ADDI	\$6 3
392		EXCH	\$7 \$6	456		XORI	\$7 8
393		ADDI	\$6 -9	457		XOR	\$9 \$7
394		SUB	\$6 \$3	458		EXCH	\$9 \$8
395		ADD	\$6 \$3	459		ADDI	\$8 1
396		ADDI	\$6 10	460		XORI	\$9 1
397		EXCH	\$7 \$6	461		EXCH	\$9 \$8
398		ADDI	\$6 -10	462		ADDI	\$8 -1
399		SUB	\$6 \$3	463	arr_con_26_bot:	EXCH	\$8 \$6
400		XORI	\$8 9996	464		XORI	\$7 8
401		ADD	\$7 \$8	465		ADDI	\$6 -3
402		XORI	\$8 9996	466		SUB	\$6 \$3
403		ADD	\$6 \$3	467		XORI	\$7 8
404		ADDI	\$6 10	468	arr_con_27:	ADDI	\$9 2
405		EXCH	\$7 \$6	469		ADD	\$9 \$7
406		ADDI	\$6 -10	470		XORI	\$7 8
407		SUB	\$6 \$3	471		EXCH	\$3 \$1
408		ADD	\$6 \$3	472		ADDI	\$1 -1
409		ADDI	\$6 15	473		EXCH	\$9 \$1
410		EXCH	\$7 \$6	474		ADDI	\$1 -1
411		ADDI	\$6 -15	475		EXCH	\$8 \$1
412		SUB	\$6 \$3	476		ADDI	\$1 -1
413		XORI	\$8 7	477		BRA	l_malloc
414		ADD	\$7 \$8	478		ADDI	\$1 1
415		XORI	\$8 7	479		EXCH	\$8 \$1
416		ADD	\$6 \$3	480		ADDI	\$1 1
417		ADDI	\$6 15	481		EXCH	\$9 \$1
418		EXCH	\$7 \$6	482		ADDI	\$1 1
419		ADDI	\$6 -15	483		EXCH	\$3 \$1
420		SUB	\$6 \$3	484		XORI	\$7 8
421	l_initLiterals_1_bot:	BRA		485		SUB	\$9 \$7
	l_initLiterals_1_top			486	arr_con_27_i:	ADDI	\$9 -2
422	l_initRules_2_top:	BRA		487		XORI	\$7 8
	l_initRules_2_bot			488		ADD	\$6 \$3
423		ADDI	\$1 1	489		ADDI	\$6 4

490		XORI	\$7 8	556		ADD	\$6 \$3
491		XOR	\$9 \$7	557		ADDI	\$6 6
492		EXCH	\$9 \$8	558		XORI	\$7 8
493		ADDI	\$8 1	559		XOR	\$9 \$7
494		XORI	\$9 1	560		EXCH	\$9 \$8
495		EXCH	\$9 \$8	561		ADDI	\$8 1
496		ADDI	\$8 -1	562		XORI	\$9 1
497	arr_con_27_bot:	EXCH	\$8 \$6	563		EXCH	\$9 \$8
498		XORI	\$7 8	564		ADDI	\$8 -1
499		ADDI	\$6 -4	565	arr_con_29_bot:	EXCH	\$8 \$6
500		SUB	\$6 \$3	566		XORI	\$7 8
501		XORI	\$7 8	567		ADDI	\$6 -6
502	arr_con_28:	ADDI	\$9 2	568		SUB	\$6 \$3
503		ADD	\$9 \$7	569		ADD	\$6 \$3
504		XORI	\$7 8	570		ADDI	\$6 3
505		EXCH	\$3 \$1	571		EXCH	\$8 \$6
506		ADDI	\$1 -1	572		XOR	\$7 \$8
507		EXCH	\$9 \$1	573		EXCH	\$8 \$6
508		ADDI	\$1 -1	574		ADDI	\$7 2
509		EXCH	\$8 \$1	575		ADD	\$7 \$0
510		ADDI	\$1 -1	576		ADDI	\$6 -3
511		BRA	l_malloc	577		SUB	\$6 \$3
512		ADDI	\$1 1	578		EXCH	\$9 \$7
513		EXCH	\$8 \$1	579		ADD	\$6 \$3
514		ADDI	\$1 1	580		ADDI	\$6 3
515		EXCH	\$9 \$1	581		SUB	\$7 \$0
516		ADDI	\$1 1	582		ADDI	\$7 -2
517		EXCH	\$3 \$1	583		EXCH	\$8 \$6
518		XORI	\$7 8	584		XOR	\$7 \$8
519		SUB	\$9 \$7	585		EXCH	\$8 \$6
520	arr_con_28_i:	ADDI	\$9 -2	586		ADDI	\$6 -3
521		XORI	\$7 8	587		SUB	\$6 \$3
522		ADD	\$6 \$3	588		XORI	\$10 1
523		ADDI	\$6 5	589	assArrElem_30:	ADD	\$9 \$10
524		XORI	\$7 8	590		XORI	\$10 1
525		XOR	\$9 \$7	591		ADD	\$6 \$3
526		EXCH	\$9 \$8	592		ADDI	\$6 3
527		ADDI	\$8 1	593		EXCH	\$8 \$6
528		XORI	\$9 1	594		XOR	\$7 \$8
529		EXCH	\$9 \$8	595		EXCH	\$8 \$6
530		ADDI	\$8 -1	596		ADDI	\$7 2
531	arr_con_28_bot:	EXCH	\$8 \$6	597		ADD	\$7 \$0
532		XORI	\$7 8	598		ADDI	\$6 -3
533		ADDI	\$6 -5	599		SUB	\$6 \$3
534		SUB	\$6 \$3	600		EXCH	\$9 \$7
535		XORI	\$7 8	601		ADD	\$6 \$3
536	arr_con_29:	ADDI	\$9 2	602		ADDI	\$6 3
537		ADD	\$9 \$7	603		SUB	\$7 \$0
538		XORI	\$7 8	604		ADDI	\$7 -2
539		EXCH	\$3 \$1	605		EXCH	\$8 \$6
540		ADDI	\$1 -1	606		XOR	\$7 \$8
541		EXCH	\$9 \$1	607		EXCH	\$8 \$6
542		ADDI	\$1 -1	608		ADDI	\$6 -3
543		EXCH	\$8 \$1	609		SUB	\$6 \$3
544		ADDI	\$1 -1	610		ADD	\$6 \$3
545		BRA	l_malloc	611		ADDI	\$6 5
546		ADDI	\$1 1	612		EXCH	\$8 \$6
547		EXCH	\$8 \$1	613		XOR	\$7 \$8
548		ADDI	\$1 1	614		EXCH	\$8 \$6
549		EXCH	\$9 \$1	615		ADDI	\$7 2
550		ADDI	\$1 1	616		ADD	\$7 \$0
551		EXCH	\$3 \$1	617		ADDI	\$6 -5
552		XORI	\$7 8	618		SUB	\$6 \$3
553		SUB	\$9 \$7	619		EXCH	\$9 \$7
554	arr_con_29_i:	ADDI	\$9 -2	620		ADD	\$6 \$3
555		XORI	\$7 8	621		ADDI	\$6 5

622		SUB	\$7 \$0	688		SUB	\$10 \$3
623		ADDI	\$7 -2	689		ADD	\$6 \$3
624		EXCH	\$8 \$6	690		ADDI	\$6 6
625		XOR	\$7 \$8	691		EXCH	\$8 \$6
626		EXCH	\$8 \$6	692		XOR	\$7 \$8
627		ADDI	\$6 -5	693		EXCH	\$8 \$6
628		SUB	\$6 \$3	694		ADDI	\$7 2
629		ADD	\$10 \$3	695		ADD	\$7 \$0
630		ADDI	\$10 10	696		ADDI	\$6 -6
631		EXCH	\$11 \$10	697		SUB	\$6 \$3
632		ADDI	\$10 -10	698		EXCH	\$9 \$7
633		SUB	\$10 \$3	699		ADD	\$6 \$3
634	assArrElem_31:	ADD	\$9 \$11	700		ADDI	\$6 6
635		ADD	\$10 \$3	701		SUB	\$7 \$0
636		ADDI	\$10 10	702		ADDI	\$7 -2
637		EXCH	\$11 \$10	703		EXCH	\$8 \$6
638		ADDI	\$10 -10	704		XOR	\$7 \$8
639		SUB	\$10 \$3	705		EXCH	\$8 \$6
640		ADD	\$6 \$3	706		ADDI	\$6 -6
641		ADDI	\$6 5	707		SUB	\$6 \$3
642		EXCH	\$8 \$6	708		ADD	\$6 \$3
643		XOR	\$7 \$8	709		ADDI	\$6 4
644		EXCH	\$8 \$6	710		EXCH	\$8 \$6
645		ADDI	\$7 2	711		XOR	\$7 \$8
646		ADD	\$7 \$0	712		EXCH	\$8 \$6
647		ADDI	\$6 -5	713		ADDI	\$7 2
648		SUB	\$6 \$3	714		ADD	\$7 \$0
649		EXCH	\$9 \$7	715		ADDI	\$6 -4
650		ADD	\$6 \$3	716		SUB	\$6 \$3
651		ADDI	\$6 5	717		EXCH	\$9 \$7
652		SUB	\$7 \$0	718		ADD	\$6 \$3
653		ADDI	\$7 -2	719		ADDI	\$6 4
654		EXCH	\$8 \$6	720		SUB	\$7 \$0
655		XOR	\$7 \$8	721		ADDI	\$7 -2
656		EXCH	\$8 \$6	722		EXCH	\$8 \$6
657		ADDI	\$6 -5	723		XOR	\$7 \$8
658		SUB	\$6 \$3	724		EXCH	\$8 \$6
659		ADD	\$6 \$3	725		ADDI	\$6 -4
660		ADDI	\$6 6	726		SUB	\$6 \$3
661		EXCH	\$8 \$6	727		XORI	\$10 2
662		XOR	\$7 \$8	728	assArrElem_33:	ADD	\$9 \$10
663		EXCH	\$8 \$6	729		XORI	\$10 2
664		ADDI	\$7 2	730		ADD	\$6 \$3
665		ADD	\$7 \$0	731		ADDI	\$6 4
666		ADDI	\$6 -6	732		EXCH	\$8 \$6
667		SUB	\$6 \$3	733		XOR	\$7 \$8
668		EXCH	\$9 \$7	734		EXCH	\$8 \$6
669		ADD	\$6 \$3	735		ADDI	\$7 2
670		ADDI	\$6 6	736		ADD	\$7 \$0
671		SUB	\$7 \$0	737		ADDI	\$6 -4
672		ADDI	\$7 -2	738		SUB	\$6 \$3
673		EXCH	\$8 \$6	739		EXCH	\$9 \$7
674		XOR	\$7 \$8	740		ADD	\$6 \$3
675		EXCH	\$8 \$6	741		ADDI	\$6 4
676		ADDI	\$6 -6	742		SUB	\$7 \$0
677		SUB	\$6 \$3	743		ADDI	\$7 -2
678		ADD	\$10 \$3	744		EXCH	\$8 \$6
679		ADDI	\$10 10	745		XOR	\$7 \$8
680		EXCH	\$11 \$10	746		EXCH	\$8 \$6
681		ADDI	\$10 -10	747		ADDI	\$6 -4
682		SUB	\$10 \$3	748		SUB	\$6 \$3
683	assArrElem_32:	ADD	\$9 \$11	749		ADD	\$6 \$3
684		ADD	\$10 \$3	750		ADDI	\$6 3
685		ADDI	\$10 10	751		XORI	\$7 1
686		EXCH	\$11 \$10	752		EXCH	\$9 \$6
687		ADDI	\$10 -10	753		XOR	\$8 \$9

754		EXCH	\$9 \$6	820		SUB	\$6 \$3
755		ADDI	\$8 2	821		ADD	\$11 \$3
756		ADD	\$8 \$7	822		ADDI	\$11 7
757		XORI	\$7 1	823		EXCH	\$12 \$11
758		ADDI	\$6 -3	824		ADDI	\$11 -7
759		SUB	\$6 \$3	825		SUB	\$11 \$3
760		EXCH	\$10 \$8	826	assArrElem_35:	ADD	\$10 \$12
761		ADD	\$6 \$3	827		ADD	\$11 \$3
762		ADDI	\$6 3	828		ADDI	\$11 7
763		XORI	\$7 1	829		EXCH	\$12 \$11
764		SUB	\$8 \$7	830		ADDI	\$11 -7
765		ADDI	\$8 -2	831		SUB	\$11 \$3
766		EXCH	\$9 \$6	832		ADD	\$6 \$3
767		XOR	\$8 \$9	833		ADDI	\$6 5
768		EXCH	\$9 \$6	834		XORI	\$7 1
769		XORI	\$7 1	835		EXCH	\$9 \$6
770		ADDI	\$6 -3	836		XOR	\$8 \$9
771		SUB	\$6 \$3	837		EXCH	\$9 \$6
772		XORI	\$11 2	838		ADDI	\$8 2
773	assArrElem_34:	ADD	\$10 \$11	839		ADD	\$8 \$7
774		XORI	\$11 2	840		XORI	\$7 1
775		ADD	\$6 \$3	841		ADDI	\$6 -5
776		ADDI	\$6 3	842		SUB	\$6 \$3
777		XORI	\$7 1	843		EXCH	\$10 \$8
778		EXCH	\$9 \$6	844		ADD	\$6 \$3
779		XOR	\$8 \$9	845		ADDI	\$6 5
780		EXCH	\$9 \$6	846		XORI	\$7 1
781		ADDI	\$8 2	847		SUB	\$8 \$7
782		ADD	\$8 \$7	848		ADDI	\$8 -2
783		XORI	\$7 1	849		EXCH	\$9 \$6
784		ADDI	\$6 -3	850		XOR	\$8 \$9
785		SUB	\$6 \$3	851		EXCH	\$9 \$6
786		EXCH	\$10 \$8	852		XORI	\$7 1
787		ADD	\$6 \$3	853		ADDI	\$6 -5
788		ADDI	\$6 3	854		SUB	\$6 \$3
789		XORI	\$7 1	855		ADD	\$6 \$3
790		SUB	\$8 \$7	856		ADDI	\$6 6
791		ADDI	\$8 -2	857		XORI	\$7 1
792		EXCH	\$9 \$6	858		EXCH	\$9 \$6
793		XOR	\$8 \$9	859		XOR	\$8 \$9
794		EXCH	\$9 \$6	860		EXCH	\$9 \$6
795		XORI	\$7 1	861		ADDI	\$8 2
796		ADDI	\$6 -3	862		ADD	\$8 \$7
797		SUB	\$6 \$3	863		XORI	\$7 1
798		ADD	\$6 \$3	864		ADDI	\$6 -6
799		ADDI	\$6 5	865		SUB	\$6 \$3
800		XORI	\$7 1	866		EXCH	\$10 \$8
801		EXCH	\$9 \$6	867		ADD	\$6 \$3
802		XOR	\$8 \$9	868		ADDI	\$6 6
803		EXCH	\$9 \$6	869		XORI	\$7 1
804		ADDI	\$8 2	870		SUB	\$8 \$7
805		ADD	\$8 \$7	871		ADDI	\$8 -2
806		XORI	\$7 1	872		EXCH	\$9 \$6
807		ADDI	\$6 -5	873		XOR	\$8 \$9
808		SUB	\$6 \$3	874		EXCH	\$9 \$6
809		EXCH	\$10 \$8	875		XORI	\$7 1
810		ADD	\$6 \$3	876		ADDI	\$6 -6
811		ADDI	\$6 5	877		SUB	\$6 \$3
812		XORI	\$7 1	878		ADD	\$11 \$3
813		SUB	\$8 \$7	879		ADDI	\$11 9
814		ADDI	\$8 -2	880		EXCH	\$12 \$11
815		EXCH	\$9 \$6	881		ADDI	\$11 -9
816		XOR	\$8 \$9	882		SUB	\$11 \$3
817		EXCH	\$9 \$6	883	assArrElem_36:	ADD	\$10 \$12
818		XORI	\$7 1	884		ADD	\$11 \$3
819		ADDI	\$6 -5	885		ADDI	\$11 9

886		EXCH	\$12 \$11	952		XORI	\$7 1
887		ADDI	\$11 -9	953		SUB	\$8 \$7
888		SUB	\$11 \$3	954		ADDI	\$8 -2
889		ADD	\$6 \$3	955		EXCH	\$9 \$6
890		ADDI	\$6 6	956		XOR	\$8 \$9
891		XORI	\$7 1	957		EXCH	\$9 \$6
892		EXCH	\$9 \$6	958		XORI	\$7 1
893		XOR	\$8 \$9	959		ADDI	\$6 -4
894		EXCH	\$9 \$6	960		SUB	\$6 \$3
895		ADDI	\$8 2	961		ADD	\$6 \$3
896		ADD	\$8 \$7	962		ADDI	\$6 3
897		XORI	\$7 1	963		XORI	\$7 2
898		ADDI	\$6 -6	964		EXCH	\$9 \$6
899		SUB	\$6 \$3	965		XOR	\$8 \$9
900		EXCH	\$10 \$8	966		EXCH	\$9 \$6
901		ADD	\$6 \$3	967		ADDI	\$8 2
902		ADDI	\$6 6	968		ADD	\$8 \$7
903		XORI	\$7 1	969		XORI	\$7 2
904		SUB	\$8 \$7	970		ADDI	\$6 -3
905		ADDI	\$8 -2	971		SUB	\$6 \$3
906		EXCH	\$9 \$6	972		EXCH	\$10 \$8
907		XOR	\$8 \$9	973		ADD	\$6 \$3
908		EXCH	\$9 \$6	974		ADDI	\$6 3
909		XORI	\$7 1	975		XORI	\$7 2
910		ADDI	\$6 -6	976		SUB	\$8 \$7
911		SUB	\$6 \$3	977		ADDI	\$8 -2
912		ADD	\$6 \$3	978		EXCH	\$9 \$6
913		ADDI	\$6 4	979		XOR	\$8 \$9
914		XORI	\$7 1	980		EXCH	\$9 \$6
915		EXCH	\$9 \$6	981		XORI	\$7 2
916		XOR	\$8 \$9	982		ADDI	\$6 -3
917		EXCH	\$9 \$6	983		SUB	\$6 \$3
918		ADDI	\$8 2	984		XORI	\$11 3
919		ADD	\$8 \$7	985	assArrElem_38:	ADD	\$10 \$11
920		XORI	\$7 1	986		XORI	\$11 3
921		ADDI	\$6 -4	987		ADD	\$6 \$3
922		SUB	\$6 \$3	988		ADDI	\$6 3
923		EXCH	\$10 \$8	989		XORI	\$7 2
924		ADD	\$6 \$3	990		EXCH	\$9 \$6
925		ADDI	\$6 4	991		XOR	\$8 \$9
926		XORI	\$7 1	992		EXCH	\$9 \$6
927		SUB	\$8 \$7	993		ADDI	\$8 2
928		ADDI	\$8 -2	994		ADD	\$8 \$7
929		EXCH	\$9 \$6	995		XORI	\$7 2
930		XOR	\$8 \$9	996		ADDI	\$6 -3
931		EXCH	\$9 \$6	997		SUB	\$6 \$3
932		XORI	\$7 1	998		EXCH	\$10 \$8
933		ADDI	\$6 -4	999		ADD	\$6 \$3
934		SUB	\$6 \$3	1000		ADDI	\$6 3
935		XORI	\$11 3	1001		XORI	\$7 2
936	assArrElem_37:	ADD	\$10 \$11	1002		SUB	\$8 \$7
937		XORI	\$11 3	1003		ADDI	\$8 -2
938		ADD	\$6 \$3	1004		EXCH	\$9 \$6
939		ADDI	\$6 4	1005		XOR	\$8 \$9
940		XORI	\$7 1	1006		EXCH	\$9 \$6
941		EXCH	\$9 \$6	1007		XORI	\$7 2
942		XOR	\$8 \$9	1008		ADDI	\$6 -3
943		EXCH	\$9 \$6	1009		SUB	\$6 \$3
944		ADDI	\$8 2	1010		ADD	\$6 \$3
945		ADD	\$8 \$7	1011		ADDI	\$6 5
946		XORI	\$7 1	1012		XORI	\$7 2
947		ADDI	\$6 -4	1013		EXCH	\$9 \$6
948		SUB	\$6 \$3	1014		XOR	\$8 \$9
949		EXCH	\$10 \$8	1015		EXCH	\$9 \$6
950		ADD	\$6 \$3	1016		ADDI	\$8 2
951		ADDI	\$6 4	1017		ADD	\$8 \$7

1018		XORI	\$7 2	1084		ADDI	\$6 6
1019		ADDI	\$6 -5	1085		XORI	\$7 2
1020		SUB	\$6 \$3	1086		EXCH	\$9 \$6
1021		EXCH	\$10 \$8	1087		XOR	\$8 \$9
1022		ADD	\$6 \$3	1088		EXCH	\$9 \$6
1023		ADDI	\$6 5	1089		ADDI	\$8 2
1024		XORI	\$7 2	1090		ADD	\$8 \$7
1025		SUB	\$8 \$7	1091		XORI	\$7 2
1026		ADDI	\$8 -2	1092		ADDI	\$6 -6
1027		EXCH	\$9 \$6	1093		SUB	\$6 \$3
1028		XOR	\$8 \$9	1094		EXCH	\$10 \$8
1029		EXCH	\$9 \$6	1095		ADD	\$6 \$3
1030		XORI	\$7 2	1096		ADDI	\$6 6
1031		ADDI	\$6 -5	1097		XORI	\$7 2
1032		SUB	\$6 \$3	1098		SUB	\$8 \$7
1033	assArrElem_39:	ADD	\$10 \$0	1099		ADDI	\$8 -2
1034		ADD	\$6 \$3	1100		EXCH	\$9 \$6
1035		ADDI	\$6 5	1101		XOR	\$8 \$9
1036		XORI	\$7 2	1102		EXCH	\$9 \$6
1037		EXCH	\$9 \$6	1103		XORI	\$7 2
1038		XOR	\$8 \$9	1104		ADDI	\$6 -6
1039		EXCH	\$9 \$6	1105		SUB	\$6 \$3
1040		ADDI	\$8 2	1106		ADD	\$6 \$3
1041		ADD	\$8 \$7	1107		ADDI	\$6 4
1042		XORI	\$7 2	1108		XORI	\$7 2
1043		ADDI	\$6 -5	1109		EXCH	\$9 \$6
1044		SUB	\$6 \$3	1110		XOR	\$8 \$9
1045		EXCH	\$10 \$8	1111		EXCH	\$9 \$6
1046		ADD	\$6 \$3	1112		ADDI	\$8 2
1047		ADDI	\$6 5	1113		ADD	\$8 \$7
1048		XORI	\$7 2	1114		XORI	\$7 2
1049		SUB	\$8 \$7	1115		ADDI	\$6 -4
1050		ADDI	\$8 -2	1116		SUB	\$6 \$3
1051		EXCH	\$9 \$6	1117		EXCH	\$10 \$8
1052		XOR	\$8 \$9	1118		ADD	\$6 \$3
1053		EXCH	\$9 \$6	1119		ADDI	\$6 4
1054		XORI	\$7 2	1120		XORI	\$7 2
1055		ADDI	\$6 -5	1121		SUB	\$8 \$7
1056		SUB	\$6 \$3	1122		ADDI	\$8 -2
1057		ADD	\$6 \$3	1123		EXCH	\$9 \$6
1058		ADDI	\$6 6	1124		XOR	\$8 \$9
1059		XORI	\$7 2	1125		EXCH	\$9 \$6
1060		EXCH	\$9 \$6	1126		XORI	\$7 2
1061		XOR	\$8 \$9	1127		ADDI	\$6 -4
1062		EXCH	\$9 \$6	1128		SUB	\$6 \$3
1063		ADDI	\$8 2	1129		XORI	\$11 4
1064		ADD	\$8 \$7	1130	assArrElem_41:	ADD	\$10 \$11
1065		XORI	\$7 2	1131		XORI	\$11 4
1066		ADDI	\$6 -6	1132		ADD	\$6 \$3
1067		SUB	\$6 \$3	1133		ADDI	\$6 4
1068		EXCH	\$10 \$8	1134		XORI	\$7 2
1069		ADD	\$6 \$3	1135		EXCH	\$9 \$6
1070		ADDI	\$6 6	1136		XOR	\$8 \$9
1071		XORI	\$7 2	1137		EXCH	\$9 \$6
1072		SUB	\$8 \$7	1138		ADDI	\$8 2
1073		ADDI	\$8 -2	1139		ADD	\$8 \$7
1074		EXCH	\$9 \$6	1140		XORI	\$7 2
1075		XOR	\$8 \$9	1141		ADDI	\$6 -4
1076		EXCH	\$9 \$6	1142		SUB	\$6 \$3
1077		XORI	\$7 2	1143		EXCH	\$10 \$8
1078		ADDI	\$6 -6	1144		ADD	\$6 \$3
1079		SUB	\$6 \$3	1145		ADDI	\$6 4
1080		XORI	\$11 1	1146		XORI	\$7 2
1081	assArrElem_40:	ADD	\$10 \$11	1147		SUB	\$8 \$7
1082		XORI	\$11 1	1148		ADDI	\$8 -2
1083		ADD	\$6 \$3	1149		EXCH	\$9 \$6

1150		XOR	\$8 \$9	1216		ADD	\$6 \$3
1151		EXCH	\$9 \$6	1217		ADDI	\$6 5
1152		XORI	\$7 2	1218		XORI	\$7 3
1153		ADDI	\$6 -4	1219		SUB	\$8 \$7
1154		SUB	\$6 \$3	1220		ADDI	\$8 -2
1155		ADD	\$6 \$3	1221		EXCH	\$9 \$6
1156		ADDI	\$6 3	1222		XOR	\$8 \$9
1157		XORI	\$7 3	1223		EXCH	\$9 \$6
1158		EXCH	\$9 \$6	1224		XORI	\$7 3
1159		XOR	\$8 \$9	1225		ADDI	\$6 -5
1160		EXCH	\$9 \$6	1226		SUB	\$6 \$3
1161		ADDI	\$8 2	1227		XORI	\$11 1
1162		ADD	\$8 \$7	1228	assArrElem_43:	ADD	\$10 \$11
1163		XORI	\$7 3	1229		XORI	\$11 1
1164		ADDI	\$6 -3	1230		ADD	\$6 \$3
1165		SUB	\$6 \$3	1231		ADDI	\$6 5
1166		EXCH	\$10 \$8	1232		XORI	\$7 3
1167		ADD	\$6 \$3	1233		EXCH	\$9 \$6
1168		ADDI	\$6 3	1234		XOR	\$8 \$9
1169		XORI	\$7 3	1235		EXCH	\$9 \$6
1170		SUB	\$8 \$7	1236		ADDI	\$8 2
1171		ADDI	\$8 -2	1237		ADD	\$8 \$7
1172		EXCH	\$9 \$6	1238		XORI	\$7 3
1173		XOR	\$8 \$9	1239		ADDI	\$6 -5
1174		EXCH	\$9 \$6	1240		SUB	\$6 \$3
1175		XORI	\$7 3	1241		EXCH	\$10 \$8
1176		ADDI	\$6 -3	1242		ADD	\$6 \$3
1177		SUB	\$6 \$3	1243		ADDI	\$6 5
1178		XORI	\$11 3	1244		XORI	\$7 3
1179	assArrElem_42:	ADD	\$10 \$11	1245		SUB	\$8 \$7
1180		XORI	\$11 3	1246		ADDI	\$8 -2
1181		ADD	\$6 \$3	1247		EXCH	\$9 \$6
1182		ADDI	\$6 3	1248		XOR	\$8 \$9
1183		XORI	\$7 3	1249		EXCH	\$9 \$6
1184		EXCH	\$9 \$6	1250		XORI	\$7 3
1185		XOR	\$8 \$9	1251		ADDI	\$6 -5
1186		EXCH	\$9 \$6	1252		SUB	\$6 \$3
1187		ADDI	\$8 2	1253		ADD	\$6 \$3
1188		ADD	\$8 \$7	1254		ADDI	\$6 6
1189		XORI	\$7 3	1255		XORI	\$7 3
1190		ADDI	\$6 -3	1256		EXCH	\$9 \$6
1191		SUB	\$6 \$3	1257		XOR	\$8 \$9
1192		EXCH	\$10 \$8	1258		EXCH	\$9 \$6
1193		ADD	\$6 \$3	1259		ADDI	\$8 2
1194		ADDI	\$6 3	1260		ADD	\$8 \$7
1195		XORI	\$7 3	1261		XORI	\$7 3
1196		SUB	\$8 \$7	1262		ADDI	\$6 -6
1197		ADDI	\$8 -2	1263		SUB	\$6 \$3
1198		EXCH	\$9 \$6	1264		EXCH	\$10 \$8
1199		XOR	\$8 \$9	1265		ADD	\$6 \$3
1200		EXCH	\$9 \$6	1266		ADDI	\$6 6
1201		XORI	\$7 3	1267		XORI	\$7 3
1202		ADDI	\$6 -3	1268		SUB	\$8 \$7
1203		SUB	\$6 \$3	1269		ADDI	\$8 -2
1204		ADD	\$6 \$3	1270		EXCH	\$9 \$6
1205		ADDI	\$6 5	1271		XOR	\$8 \$9
1206		XORI	\$7 3	1272		EXCH	\$9 \$6
1207		EXCH	\$9 \$6	1273		XORI	\$7 3
1208		XOR	\$8 \$9	1274		ADDI	\$6 -6
1209		EXCH	\$9 \$6	1275		SUB	\$6 \$3
1210		ADDI	\$8 2	1276	assArrElem_44:	ADD	\$10 \$0
1211		ADD	\$8 \$7	1277		ADD	\$6 \$3
1212		XORI	\$7 3	1278		ADDI	\$6 6
1213		ADDI	\$6 -5	1279		XORI	\$7 3
1214		SUB	\$6 \$3	1280		EXCH	\$9 \$6
1215		EXCH	\$10 \$8	1281		XOR	\$8 \$9

1282		EXCH	\$9 \$6	1348		SUB	\$6 \$3
1283		ADDI	\$8 2	1349		ADD	\$6 \$3
1284		ADD	\$8 \$7	1350		ADDI	\$6 3
1285		XORI	\$7 3	1351		XORI	\$7 4
1286		ADDI	\$6 -6	1352		EXCH	\$9 \$6
1287		SUB	\$6 \$3	1353		XOR	\$8 \$9
1288		EXCH	\$10 \$8	1354		EXCH	\$9 \$6
1289		ADD	\$6 \$3	1355		ADDI	\$8 2
1290		ADDI	\$6 6	1356		ADD	\$8 \$7
1291		XORI	\$7 3	1357		XORI	\$7 4
1292		SUB	\$8 \$7	1358		ADDI	\$6 -3
1293		ADDI	\$8 -2	1359		SUB	\$6 \$3
1294		EXCH	\$9 \$6	1360		EXCH	\$10 \$8
1295		XOR	\$8 \$9	1361		ADD	\$6 \$3
1296		EXCH	\$9 \$6	1362		ADDI	\$6 3
1297		XORI	\$7 3	1363		XORI	\$7 4
1298		ADDI	\$6 -6	1364		SUB	\$8 \$7
1299		SUB	\$6 \$3	1365		ADDI	\$8 -2
1300		ADD	\$6 \$3	1366		EXCH	\$9 \$6
1301		ADDI	\$6 4	1367		XOR	\$8 \$9
1302		XORI	\$7 3	1368		EXCH	\$9 \$6
1303		EXCH	\$9 \$6	1369		XORI	\$7 4
1304		XOR	\$8 \$9	1370		ADDI	\$6 -3
1305		EXCH	\$9 \$6	1371		SUB	\$6 \$3
1306		ADDI	\$8 2	1372		XORI	\$11 3
1307		ADD	\$8 \$7	1373	assArrElem_46:	ADD	\$10 \$11
1308		XORI	\$7 3	1374		XORI	\$11 3
1309		ADDI	\$6 -4	1375		ADD	\$6 \$3
1310		SUB	\$6 \$3	1376		ADDI	\$6 3
1311		EXCH	\$10 \$8	1377		XORI	\$7 4
1312		ADD	\$6 \$3	1378		EXCH	\$9 \$6
1313		ADDI	\$6 4	1379		XOR	\$8 \$9
1314		XORI	\$7 3	1380		EXCH	\$9 \$6
1315		SUB	\$8 \$7	1381		ADDI	\$8 2
1316		ADDI	\$8 -2	1382		ADD	\$8 \$7
1317		EXCH	\$9 \$6	1383		XORI	\$7 4
1318		XOR	\$8 \$9	1384		ADDI	\$6 -3
1319		EXCH	\$9 \$6	1385		SUB	\$6 \$3
1320		XORI	\$7 3	1386		EXCH	\$10 \$8
1321		ADDI	\$6 -4	1387		ADD	\$6 \$3
1322		SUB	\$6 \$3	1388		ADDI	\$6 3
1323		XORI	\$11 2	1389		XORI	\$7 4
1324	assArrElem_45:	ADD	\$10 \$11	1390		SUB	\$8 \$7
1325		XORI	\$11 2	1391		ADDI	\$8 -2
1326		ADD	\$6 \$3	1392		EXCH	\$9 \$6
1327		ADDI	\$6 4	1393		XOR	\$8 \$9
1328		XORI	\$7 3	1394		EXCH	\$9 \$6
1329		EXCH	\$9 \$6	1395		XORI	\$7 4
1330		XOR	\$8 \$9	1396		ADDI	\$6 -3
1331		EXCH	\$9 \$6	1397		SUB	\$6 \$3
1332		ADDI	\$8 2	1398		ADD	\$6 \$3
1333		ADD	\$8 \$7	1399		ADDI	\$6 5
1334		XORI	\$7 3	1400		XORI	\$7 4
1335		ADDI	\$6 -4	1401		EXCH	\$9 \$6
1336		SUB	\$6 \$3	1402		XOR	\$8 \$9
1337		EXCH	\$10 \$8	1403		EXCH	\$9 \$6
1338		ADD	\$6 \$3	1404		ADDI	\$8 2
1339		ADDI	\$6 4	1405		ADD	\$8 \$7
1340		XORI	\$7 3	1406		XORI	\$7 4
1341		SUB	\$8 \$7	1407		ADDI	\$6 -5
1342		ADDI	\$8 -2	1408		SUB	\$6 \$3
1343		EXCH	\$9 \$6	1409		EXCH	\$10 \$8
1344		XOR	\$8 \$9	1410		ADD	\$6 \$3
1345		EXCH	\$9 \$6	1411		ADDI	\$6 5
1346		XORI	\$7 3	1412		XORI	\$7 4
1347		ADDI	\$6 -4	1413		SUB	\$8 \$7

1414		ADDI	\$8 -2	1480		EXCH	\$12 \$11
1415		EXCH	\$9 \$6	1481		ADDI	\$11 -10
1416		XOR	\$8 \$9	1482		SUB	\$11 \$3
1417		EXCH	\$9 \$6	1483	assArrElem_48:	ADD	\$10 \$12
1418		XORI	\$7 4	1484		ADD	\$11 \$3
1419		ADDI	\$6 -5	1485		ADDI	\$11 10
1420		SUB	\$6 \$3	1486		EXCH	\$12 \$11
1421		ADD	\$11 \$3	1487		ADDI	\$11 -10
1422		ADDI	\$11 10	1488		SUB	\$11 \$3
1423		EXCH	\$12 \$11	1489		ADD	\$6 \$3
1424		ADDI	\$11 -10	1490		ADDI	\$6 6
1425		SUB	\$11 \$3	1491		XORI	\$7 4
1426	assArrElem_47:	ADD	\$10 \$12	1492		EXCH	\$9 \$6
1427		ADD	\$11 \$3	1493		XOR	\$8 \$9
1428		ADDI	\$11 10	1494		EXCH	\$9 \$6
1429		EXCH	\$12 \$11	1495		ADDI	\$8 2
1430		ADDI	\$11 -10	1496		ADD	\$8 \$7
1431		SUB	\$11 \$3	1497		XORI	\$7 4
1432		ADD	\$6 \$3	1498		ADDI	\$6 -6
1433		ADDI	\$6 5	1499		SUB	\$6 \$3
1434		XORI	\$7 4	1500		EXCH	\$10 \$8
1435		EXCH	\$9 \$6	1501		ADD	\$6 \$3
1436		XOR	\$8 \$9	1502		ADDI	\$6 6
1437		EXCH	\$9 \$6	1503		XORI	\$7 4
1438		ADDI	\$8 2	1504		SUB	\$8 \$7
1439		ADD	\$8 \$7	1505		ADDI	\$8 -2
1440		XORI	\$7 4	1506		EXCH	\$9 \$6
1441		ADDI	\$6 -5	1507		XOR	\$8 \$9
1442		SUB	\$6 \$3	1508		EXCH	\$9 \$6
1443		EXCH	\$10 \$8	1509		XORI	\$7 4
1444		ADD	\$6 \$3	1510		ADDI	\$6 -6
1445		ADDI	\$6 5	1511		SUB	\$6 \$3
1446		XORI	\$7 4	1512		ADD	\$6 \$3
1447		SUB	\$8 \$7	1513		ADDI	\$6 4
1448		ADDI	\$8 -2	1514		XORI	\$7 4
1449		EXCH	\$9 \$6	1515		EXCH	\$9 \$6
1450		XOR	\$8 \$9	1516		XOR	\$8 \$9
1451		EXCH	\$9 \$6	1517		EXCH	\$9 \$6
1452		XORI	\$7 4	1518		ADDI	\$8 2
1453		ADDI	\$6 -5	1519		ADD	\$8 \$7
1454		SUB	\$6 \$3	1520		XORI	\$7 4
1455		ADD	\$6 \$3	1521		ADDI	\$6 -4
1456		ADDI	\$6 6	1522		SUB	\$6 \$3
1457		XORI	\$7 4	1523		EXCH	\$10 \$8
1458		EXCH	\$9 \$6	1524		ADD	\$6 \$3
1459		XOR	\$8 \$9	1525		ADDI	\$6 4
1460		EXCH	\$9 \$6	1526		XORI	\$7 4
1461		ADDI	\$8 2	1527		SUB	\$8 \$7
1462		ADD	\$8 \$7	1528		ADDI	\$8 -2
1463		XORI	\$7 4	1529		EXCH	\$9 \$6
1464		ADDI	\$6 -6	1530		XOR	\$8 \$9
1465		SUB	\$6 \$3	1531		EXCH	\$9 \$6
1466		EXCH	\$10 \$8	1532		XORI	\$7 4
1467		ADD	\$6 \$3	1533		ADDI	\$6 -4
1468		ADDI	\$6 6	1534		SUB	\$6 \$3
1469		XORI	\$7 4	1535		XORI	\$11 4
1470		SUB	\$8 \$7	1536	assArrElem_49:	ADD	\$10 \$11
1471		ADDI	\$8 -2	1537		XORI	\$11 4
1472		EXCH	\$9 \$6	1538		ADD	\$6 \$3
1473		XOR	\$8 \$9	1539		ADDI	\$6 4
1474		EXCH	\$9 \$6	1540		XORI	\$7 4
1475		XORI	\$7 4	1541		EXCH	\$9 \$6
1476		ADDI	\$6 -6	1542		XOR	\$8 \$9
1477		SUB	\$6 \$3	1543		EXCH	\$9 \$6
1478		ADD	\$11 \$3	1544		ADDI	\$8 2
1479		ADDI	\$11 10	1545		ADD	\$8 \$7

1546		XORI	\$7 4	1612		XORI	\$7 5
1547		ADDI	\$6 -4	1613		EXCH	\$9 \$6
1548		SUB	\$6 \$3	1614		XOR	\$8 \$9
1549		EXCH	\$10 \$8	1615		EXCH	\$9 \$6
1550		ADD	\$6 \$3	1616		ADDI	\$8 2
1551		ADDI	\$6 4	1617		ADD	\$8 \$7
1552		XORI	\$7 4	1618		XORI	\$7 5
1553		SUB	\$8 \$7	1619		ADDI	\$6 -5
1554		ADDI	\$8 -2	1620		SUB	\$6 \$3
1555		EXCH	\$9 \$6	1621		EXCH	\$10 \$8
1556		XOR	\$8 \$9	1622		ADD	\$6 \$3
1557		EXCH	\$9 \$6	1623		ADDI	\$6 5
1558		XORI	\$7 4	1624		XORI	\$7 5
1559		ADDI	\$6 -4	1625		SUB	\$8 \$7
1560		SUB	\$6 \$3	1626		ADDI	\$8 -2
1561		ADD	\$6 \$3	1627		EXCH	\$9 \$6
1562		ADDI	\$6 3	1628		XOR	\$8 \$9
1563		XORI	\$7 5	1629		EXCH	\$9 \$6
1564		EXCH	\$9 \$6	1630		XORI	\$7 5
1565		XOR	\$8 \$9	1631		ADDI	\$6 -5
1566		EXCH	\$9 \$6	1632		SUB	\$6 \$3
1567		ADDI	\$8 2	1633		ADD	\$11 \$3
1568		ADD	\$8 \$7	1634		ADDI	\$11 7
1569		XORI	\$7 5	1635		EXCH	\$12 \$11
1570		ADDI	\$6 -3	1636		ADDI	\$11 -7
1571		SUB	\$6 \$3	1637		SUB	\$11 \$3
1572		EXCH	\$10 \$8	1638	assArrElem_51:	ADD	\$10 \$12
1573		ADD	\$6 \$3	1639		ADD	\$11 \$3
1574		ADDI	\$6 3	1640		ADDI	\$11 7
1575		XORI	\$7 5	1641		EXCH	\$12 \$11
1576		SUB	\$8 \$7	1642		ADDI	\$11 -7
1577		ADDI	\$8 -2	1643		SUB	\$11 \$3
1578		EXCH	\$9 \$6	1644		ADD	\$6 \$3
1579		XOR	\$8 \$9	1645		ADDI	\$6 5
1580		EXCH	\$9 \$6	1646		XORI	\$7 5
1581		XORI	\$7 5	1647		EXCH	\$9 \$6
1582		ADDI	\$6 -3	1648		XOR	\$8 \$9
1583		SUB	\$6 \$3	1649		EXCH	\$9 \$6
1584		XORI	\$11 4	1650		ADDI	\$8 2
1585	assArrElem_50:	ADD	\$10 \$11	1651		ADD	\$8 \$7
1586		XORI	\$11 4	1652		XORI	\$7 5
1587		ADD	\$6 \$3	1653		ADDI	\$6 -5
1588		ADDI	\$6 3	1654		SUB	\$6 \$3
1589		XORI	\$7 5	1655		EXCH	\$10 \$8
1590		EXCH	\$9 \$6	1656		ADD	\$6 \$3
1591		XOR	\$8 \$9	1657		ADDI	\$6 5
1592		EXCH	\$9 \$6	1658		XORI	\$7 5
1593		ADDI	\$8 2	1659		SUB	\$8 \$7
1594		ADD	\$8 \$7	1660		ADDI	\$8 -2
1595		XORI	\$7 5	1661		EXCH	\$9 \$6
1596		ADDI	\$6 -3	1662		XOR	\$8 \$9
1597		SUB	\$6 \$3	1663		EXCH	\$9 \$6
1598		EXCH	\$10 \$8	1664		XORI	\$7 5
1599		ADD	\$6 \$3	1665		ADDI	\$6 -5
1600		ADDI	\$6 3	1666		SUB	\$6 \$3
1601		XORI	\$7 5	1667		ADD	\$6 \$3
1602		SUB	\$8 \$7	1668		ADDI	\$6 6
1603		ADDI	\$8 -2	1669		XORI	\$7 5
1604		EXCH	\$9 \$6	1670		EXCH	\$9 \$6
1605		XOR	\$8 \$9	1671		XOR	\$8 \$9
1606		EXCH	\$9 \$6	1672		EXCH	\$9 \$6
1607		XORI	\$7 5	1673		ADDI	\$8 2
1608		ADDI	\$6 -3	1674		ADD	\$8 \$7
1609		SUB	\$6 \$3	1675		XORI	\$7 5
1610		ADD	\$6 \$3	1676		ADDI	\$6 -6
1611		ADDI	\$6 5	1677		SUB	\$6 \$3

1678		EXCH	\$10 \$8	1744		XORI	\$7 5
1679		ADD	\$6 \$3	1745		ADDI	\$6 -4
1680		ADDI	\$6 6	1746		SUB	\$6 \$3
1681		XORI	\$7 5	1747		XORI	\$11 5
1682		SUB	\$8 \$7	1748	assArrElem_53:	ADD	\$10 \$11
1683		ADDI	\$8 -2	1749		XORI	\$11 5
1684		EXCH	\$9 \$6	1750		ADD	\$6 \$3
1685		XOR	\$8 \$9	1751		ADDI	\$6 4
1686		EXCH	\$9 \$6	1752		XORI	\$7 5
1687		XORI	\$7 5	1753		EXCH	\$9 \$6
1688		ADDI	\$6 -6	1754		XOR	\$8 \$9
1689		SUB	\$6 \$3	1755		EXCH	\$9 \$6
1690		ADD	\$11 \$3	1756		ADDI	\$8 2
1691		ADDI	\$11 8	1757		ADD	\$8 \$7
1692		EXCH	\$12 \$11	1758		XORI	\$7 5
1693		ADDI	\$11 -8	1759		ADDI	\$6 -4
1694		SUB	\$11 \$3	1760		SUB	\$6 \$3
1695	assArrElem_52:	ADD	\$10 \$12	1761		EXCH	\$10 \$8
1696		ADD	\$11 \$3	1762		ADD	\$6 \$3
1697		ADDI	\$11 8	1763		ADDI	\$6 4
1698		EXCH	\$12 \$11	1764		XORI	\$7 5
1699		ADDI	\$11 -8	1765		SUB	\$8 \$7
1700		SUB	\$11 \$3	1766		ADDI	\$8 -2
1701		ADD	\$6 \$3	1767		EXCH	\$9 \$6
1702		ADDI	\$6 6	1768		XOR	\$8 \$9
1703		XORI	\$7 5	1769		EXCH	\$9 \$6
1704		EXCH	\$9 \$6	1770		XORI	\$7 5
1705		XOR	\$8 \$9	1771		ADDI	\$6 -4
1706		EXCH	\$9 \$6	1772		SUB	\$6 \$3
1707		ADDI	\$8 2	1773		ADD	\$6 \$3
1708		ADD	\$8 \$7	1774		ADDI	\$6 3
1709		XORI	\$7 5	1775		XORI	\$7 6
1710		ADDI	\$6 -6	1776		EXCH	\$9 \$6
1711		SUB	\$6 \$3	1777		XOR	\$8 \$9
1712		EXCH	\$10 \$8	1778		EXCH	\$9 \$6
1713		ADD	\$6 \$3	1779		ADDI	\$8 2
1714		ADDI	\$6 6	1780		ADD	\$8 \$7
1715		XORI	\$7 5	1781		XORI	\$7 6
1716		SUB	\$8 \$7	1782		ADDI	\$6 -3
1717		ADDI	\$8 -2	1783		SUB	\$6 \$3
1718		EXCH	\$9 \$6	1784		EXCH	\$10 \$8
1719		XOR	\$8 \$9	1785		ADD	\$6 \$3
1720		EXCH	\$9 \$6	1786		ADDI	\$6 3
1721		XORI	\$7 5	1787		XORI	\$7 6
1722		ADDI	\$6 -6	1788		SUB	\$8 \$7
1723		SUB	\$6 \$3	1789		ADDI	\$8 -2
1724		ADD	\$6 \$3	1790		EXCH	\$9 \$6
1725		ADDI	\$6 4	1791		XOR	\$8 \$9
1726		XORI	\$7 5	1792		EXCH	\$9 \$6
1727		EXCH	\$9 \$6	1793		XORI	\$7 6
1728		XOR	\$8 \$9	1794		ADDI	\$6 -3
1729		EXCH	\$9 \$6	1795		SUB	\$6 \$3
1730		ADDI	\$8 2	1796		XORI	\$11 5
1731		ADD	\$8 \$7	1797	assArrElem_54:	ADD	\$10 \$11
1732		XORI	\$7 5	1798		XORI	\$11 5
1733		ADDI	\$6 -4	1799		ADD	\$6 \$3
1734		SUB	\$6 \$3	1800		ADDI	\$6 3
1735		EXCH	\$10 \$8	1801		XORI	\$7 6
1736		ADD	\$6 \$3	1802		EXCH	\$9 \$6
1737		ADDI	\$6 4	1803		XOR	\$8 \$9
1738		XORI	\$7 5	1804		EXCH	\$9 \$6
1739		SUB	\$8 \$7	1805		ADDI	\$8 2
1740		ADDI	\$8 -2	1806		ADD	\$8 \$7
1741		EXCH	\$9 \$6	1807		XORI	\$7 6
1742		XOR	\$8 \$9	1808		ADDI	\$6 -3
1743		EXCH	\$9 \$6	1809		SUB	\$6 \$3

1810		EXCH	\$10 \$8	1876		ADD	\$8 \$7
1811		ADD	\$6 \$3	1877		XORI	\$7 6
1812		ADDI	\$6 3	1878		ADDI	\$6 -6
1813		XORI	\$7 6	1879		SUB	\$6 \$3
1814		SUB	\$8 \$7	1880		EXCH	\$10 \$8
1815		ADDI	\$8 -2	1881		ADD	\$6 \$3
1816		EXCH	\$9 \$6	1882		ADDI	\$6 6
1817		XOR	\$8 \$9	1883		XORI	\$7 6
1818		EXCH	\$9 \$6	1884		SUB	\$8 \$7
1819		XORI	\$7 6	1885		ADDI	\$8 -2
1820		ADDI	\$6 -3	1886		EXCH	\$9 \$6
1821		SUB	\$6 \$3	1887		XOR	\$8 \$9
1822		ADD	\$6 \$3	1888		EXCH	\$9 \$6
1823		ADDI	\$6 5	1889		XORI	\$7 6
1824		XORI	\$7 6	1890		ADDI	\$6 -6
1825		EXCH	\$9 \$6	1891		SUB	\$6 \$3
1826		XOR	\$8 \$9	1892	assArrElem_56:	ADD	\$10 \$0
1827		EXCH	\$9 \$6	1893		ADD	\$6 \$3
1828		ADDI	\$8 2	1894		ADDI	\$6 6
1829		ADD	\$8 \$7	1895		XORI	\$7 6
1830		XORI	\$7 6	1896		EXCH	\$9 \$6
1831		ADDI	\$6 -5	1897		XOR	\$8 \$9
1832		SUB	\$6 \$3	1898		EXCH	\$9 \$6
1833		EXCH	\$10 \$8	1899		ADDI	\$8 2
1834		ADD	\$6 \$3	1900		ADD	\$8 \$7
1835		ADDI	\$6 5	1901		XORI	\$7 6
1836		XORI	\$7 6	1902		ADDI	\$6 -6
1837		SUB	\$8 \$7	1903		SUB	\$6 \$3
1838		ADDI	\$8 -2	1904		EXCH	\$10 \$8
1839		EXCH	\$9 \$6	1905		ADD	\$6 \$3
1840		XOR	\$8 \$9	1906		ADDI	\$6 6
1841		EXCH	\$9 \$6	1907		XORI	\$7 6
1842		XORI	\$7 6	1908		SUB	\$8 \$7
1843		ADDI	\$6 -5	1909		ADDI	\$8 -2
1844		SUB	\$6 \$3	1910		EXCH	\$9 \$6
1845	assArrElem_55:	ADD	\$10 \$0	1911		XOR	\$8 \$9
1846		ADD	\$6 \$3	1912		EXCH	\$9 \$6
1847		ADDI	\$6 5	1913		XORI	\$7 6
1848		XORI	\$7 6	1914		ADDI	\$6 -6
1849		EXCH	\$9 \$6	1915		SUB	\$6 \$3
1850		XOR	\$8 \$9	1916		ADD	\$6 \$3
1851		EXCH	\$9 \$6	1917		ADDI	\$6 4
1852		ADDI	\$8 2	1918		XORI	\$7 6
1853		ADD	\$8 \$7	1919		EXCH	\$9 \$6
1854		XORI	\$7 6	1920		XOR	\$8 \$9
1855		ADDI	\$6 -5	1921		EXCH	\$9 \$6
1856		SUB	\$6 \$3	1922		ADDI	\$8 2
1857		EXCH	\$10 \$8	1923		ADD	\$8 \$7
1858		ADD	\$6 \$3	1924		XORI	\$7 6
1859		ADDI	\$6 5	1925		ADDI	\$6 -4
1860		XORI	\$7 6	1926		SUB	\$6 \$3
1861		SUB	\$8 \$7	1927		EXCH	\$10 \$8
1862		ADDI	\$8 -2	1928		ADD	\$6 \$3
1863		EXCH	\$9 \$6	1929		ADDI	\$6 4
1864		XOR	\$8 \$9	1930		XORI	\$7 6
1865		EXCH	\$9 \$6	1931		SUB	\$8 \$7
1866		XORI	\$7 6	1932		ADDI	\$8 -2
1867		ADDI	\$6 -5	1933		EXCH	\$9 \$6
1868		SUB	\$6 \$3	1934		XOR	\$8 \$9
1869		ADD	\$6 \$3	1935		EXCH	\$9 \$6
1870		ADDI	\$6 6	1936		XORI	\$7 6
1871		XORI	\$7 6	1937		ADDI	\$6 -4
1872		EXCH	\$9 \$6	1938		SUB	\$6 \$3
1873		XOR	\$8 \$9	1939		XORI	\$11 4
1874		EXCH	\$9 \$6	1940	assArrElem_57:	ADD	\$10 \$11
1875		ADDI	\$8 2	1941		XORI	\$11 4

1942	ADD	\$6 \$3	2008	EXCH	\$9 \$6
1943	ADDI	\$6 4	2009	XOR	\$8 \$9
1944	XORI	\$7 6	2010	EXCH	\$9 \$6
1945	EXCH	\$9 \$6	2011	XORI	\$7 7
1946	XOR	\$8 \$9	2012	ADDI	\$6 -3
1947	EXCH	\$9 \$6	2013	SUB	\$6 \$3
1948	ADDI	\$8 2	2014	ADD	\$6 \$3
1949	ADD	\$8 \$7	2015	ADDI	\$6 5
1950	XORI	\$7 6	2016	XORI	\$7 7
1951	ADDI	\$6 -4	2017	EXCH	\$9 \$6
1952	SUB	\$6 \$3	2018	XOR	\$8 \$9
1953	EXCH	\$10 \$8	2019	EXCH	\$9 \$6
1954	ADD	\$6 \$3	2020	ADDI	\$8 2
1955	ADDI	\$6 4	2021	ADD	\$8 \$7
1956	XORI	\$7 6	2022	XORI	\$7 7
1957	SUB	\$8 \$7	2023	ADDI	\$6 -5
1958	ADDI	\$8 -2	2024	SUB	\$6 \$3
1959	EXCH	\$9 \$6	2025	EXCH	\$10 \$8
1960	XOR	\$8 \$9	2026	ADD	\$6 \$3
1961	EXCH	\$9 \$6	2027	ADDI	\$6 5
1962	XORI	\$7 6	2028	XORI	\$7 7
1963	ADDI	\$6 -4	2029	SUB	\$8 \$7
1964	SUB	\$6 \$3	2030	ADDI	\$8 -2
1965	ADD	\$6 \$3	2031	EXCH	\$9 \$6
1966	ADDI	\$6 3	2032	XOR	\$8 \$9
1967	XORI	\$7 7	2033	EXCH	\$9 \$6
1968	EXCH	\$9 \$6	2034	XORI	\$7 7
1969	XOR	\$8 \$9	2035	ADDI	\$6 -5
1970	EXCH	\$9 \$6	2036	SUB	\$6 \$3
1971	ADDI	\$8 2	2037	ADD	\$11 \$3
1972	ADD	\$8 \$7	2038	ADDI	\$11 10
1973	XORI	\$7 7	2039	EXCH	\$12 \$11
1974	ADDI	\$6 -3	2040	ADDI	\$11 -10
1975	SUB	\$6 \$3	2041	SUB	\$11 \$3
1976	EXCH	\$10 \$8	2042	ADD	\$10 \$12
1977	ADD	\$6 \$3	2043	ADD	\$11 \$3
1978	ADDI	\$6 3	2044	ADDI	\$11 10
1979	XORI	\$7 7	2045	EXCH	\$12 \$11
1980	SUB	\$8 \$7	2046	ADDI	\$11 -10
1981	ADDI	\$8 -2	2047	SUB	\$11 \$3
1982	EXCH	\$9 \$6	2048	ADD	\$6 \$3
1983	XOR	\$8 \$9	2049	ADDI	\$6 5
1984	EXCH	\$9 \$6	2050	XORI	\$7 7
1985	XORI	\$7 7	2051	EXCH	\$9 \$6
1986	ADDI	\$6 -3	2052	XOR	\$8 \$9
1987	SUB	\$6 \$3	2053	EXCH	\$9 \$6
1988	XORI	\$11 5	2054	ADDI	\$8 2
1989	ADD	\$10 \$11	2055	ADD	\$8 \$7
1990	XORI	\$11 5	2056	XORI	\$7 7
1991	ADD	\$6 \$3	2057	ADDI	\$6 -5
1992	ADDI	\$6 3	2058	SUB	\$6 \$3
1993	XORI	\$7 7	2059	EXCH	\$10 \$8
1994	EXCH	\$9 \$6	2060	ADD	\$6 \$3
1995	XOR	\$8 \$9	2061	ADDI	\$6 5
1996	EXCH	\$9 \$6	2062	XORI	\$7 7
1997	ADDI	\$8 2	2063	SUB	\$8 \$7
1998	ADD	\$8 \$7	2064	ADDI	\$8 -2
1999	XORI	\$7 7	2065	EXCH	\$9 \$6
2000	ADDI	\$6 -3	2066	XOR	\$8 \$9
2001	SUB	\$6 \$3	2067	EXCH	\$9 \$6
2002	EXCH	\$10 \$8	2068	XORI	\$7 7
2003	ADD	\$6 \$3	2069	ADDI	\$6 -5
2004	ADDI	\$6 3	2070	SUB	\$6 \$3
2005	XORI	\$7 7	2071	ADD	\$6 \$3
2006	SUB	\$8 \$7	2072	ADDI	\$6 6
2007	ADDI	\$8 -2	2073	XORI	\$7 7

2074		EXCH	\$9 \$6	2140		ADD	\$6 \$3
2075		XOR	\$8 \$9	2141		ADDI	\$6 4
2076		EXCH	\$9 \$6	2142		XORI	\$7 7
2077		ADDI	\$8 2	2143		SUB	\$8 \$7
2078		ADD	\$8 \$7	2144		ADDI	\$8 -2
2079		XORI	\$7 7	2145		EXCH	\$9 \$6
2080		ADDI	\$6 -6	2146		XOR	\$8 \$9
2081		SUB	\$6 \$3	2147		EXCH	\$9 \$6
2082		EXCH	\$10 \$8	2148		XORI	\$7 7
2083		ADD	\$6 \$3	2149		ADDI	\$6 -4
2084		ADDI	\$6 6	2150		SUB	\$6 \$3
2085		XORI	\$7 7	2151		XORI	\$11 6
2086		SUB	\$8 \$7	2152	assArrElem_61:	ADD	\$10 \$11
2087		ADDI	\$8 -2	2153		XORI	\$11 6
2088		EXCH	\$9 \$6	2154		ADD	\$6 \$3
2089		XOR	\$8 \$9	2155		ADDI	\$6 4
2090		EXCH	\$9 \$6	2156		XORI	\$7 7
2091		XORI	\$7 7	2157		EXCH	\$9 \$6
2092		ADDI	\$6 -6	2158		XOR	\$8 \$9
2093		SUB	\$6 \$3	2159		EXCH	\$9 \$6
2094		ADD	\$11 \$3	2160		ADDI	\$8 2
2095		ADDI	\$11 10	2161		ADD	\$8 \$7
2096		EXCH	\$12 \$11	2162		XORI	\$7 7
2097		ADDI	\$11 -10	2163		ADDI	\$6 -4
2098		SUB	\$11 \$3	2164		SUB	\$6 \$3
2099	assArrElem_60:	ADD	\$10 \$12	2165		EXCH	\$10 \$8
2100		ADD	\$11 \$3	2166		ADD	\$6 \$3
2101		ADDI	\$11 10	2167		ADDI	\$6 4
2102		EXCH	\$12 \$11	2168		XORI	\$7 7
2103		ADDI	\$11 -10	2169		SUB	\$8 \$7
2104		SUB	\$11 \$3	2170		ADDI	\$8 -2
2105		ADD	\$6 \$3	2171		EXCH	\$9 \$6
2106		ADDI	\$6 6	2172		XOR	\$8 \$9
2107		XORI	\$7 7	2173		EXCH	\$9 \$6
2108		EXCH	\$9 \$6	2174		XORI	\$7 7
2109		XOR	\$8 \$9	2175		ADDI	\$6 -4
2110		EXCH	\$9 \$6	2176		SUB	\$6 \$3
2111		ADDI	\$8 2	2177	l_initRules_2_bot:	BRA	
2112		ADD	\$8 \$7		l_initRules_2_top		
2113		XORI	\$7 7	2178	l_initTape_3_top:	BRA	
2114		ADDI	\$6 -6		l_initTape_3_bot		
2115		SUB	\$6 \$3	2179		ADDI	\$1 1
2116		EXCH	\$10 \$8	2180		EXCH	\$2 \$1
2117		ADD	\$6 \$3	2181		EXCH	\$3 \$1
2118		ADDI	\$6 6	2182		ADDI	\$1 -1
2119		XORI	\$7 7	2183	l_initTape_3:	SWAPBR	\$2
2120		SUB	\$8 \$7	2184		NEG	\$2
2121		ADDI	\$8 -2	2185		ADDI	\$1 1
2122		EXCH	\$9 \$6	2186		EXCH	\$3 \$1
2123		XOR	\$8 \$9	2187		EXCH	\$2 \$1
2124		EXCH	\$9 \$6	2188		ADDI	\$1 -1
2125		XORI	\$7 7	2189	localBlock_149:	XOR	\$6 \$1
2126		ADDI	\$6 -6	2190		XOR	\$7 \$0
2127		SUB	\$6 \$3	2191		EXCH	\$7 \$1
2128		ADD	\$6 \$3	2192		ADDI	\$1 -1
2129		ADDI	\$6 4	2193	localBlock_148:	XOR	\$7 \$1
2130		XORI	\$7 7	2194		XOR	\$8 \$0
2131		EXCH	\$9 \$6	2195		EXCH	\$8 \$1
2132		XOR	\$8 \$9	2196		ADDI	\$1 -1
2133		EXCH	\$9 \$6	2197	localBlock_147:	XOR	\$8 \$1
2134		ADDI	\$8 2	2198		XOR	\$9 \$0
2135		ADD	\$8 \$7	2199		EXCH	\$9 \$1
2136		XORI	\$7 7	2200		ADDI	\$1 -1
2137		ADDI	\$6 -4	2201	localBlock_146:	XOR	\$9 \$1
2138		SUB	\$6 \$3	2202		XOR	\$10 \$0
2139		EXCH	\$10 \$8	2203		EXCH	\$10 \$1

2204		ADDI	\$1 -1	2270		EXCH	\$11 \$1
2205	localBlock_145:	XOR	\$10 \$1	2271		ADDI	\$1 1
2206		XOR	\$11 \$0	2272		EXCH	\$12 \$1
2207		EXCH	\$11 \$1	2273	obj_con_63_i:	ADDI	\$12 -8
2208		ADDI	\$1 -1	2274		ADDI	\$1 1
2209		EXCH	\$3 \$1	2275		EXCH	\$6 \$1
2210		ADDI	\$1 -1	2276		ADDI	\$1 1
2211		EXCH	\$10 \$1	2277		EXCH	\$7 \$1
2212		ADDI	\$1 -1	2278		ADDI	\$1 1
2213		EXCH	\$9 \$1	2279		EXCH	\$8 \$1
2214		ADDI	\$1 -1	2280		ADDI	\$1 1
2215		EXCH	\$8 \$1	2281		EXCH	\$9 \$1
2216		ADDI	\$1 -1	2282		ADDI	\$1 1
2217		EXCH	\$7 \$1	2283		EXCH	\$10 \$1
2218		ADDI	\$1 -1	2284		ADDI	\$1 1
2219		EXCH	\$6 \$1	2285		EXCH	\$3 \$1
2220		ADDI	\$1 -1	2286		XORI	\$12 10
2221	obj_con_62:	ADDI	\$12 8	2287		EXCH	\$12 \$11
2222		EXCH	\$12 \$1	2288		ADDI	\$11 1
2223		ADDI	\$1 -1	2289		XORI	\$12 1
2224		EXCH	\$11 \$1	2290		EXCH	\$12 \$11
2225		ADDI	\$1 -1	2291	obj_con_63_bot:	ADDI	\$11 -1
2226		BRA	l_malloc	2292		EXCH	\$11 \$7
2227		ADDI	\$1 1	2293		EXCH	\$3 \$1
2228		EXCH	\$11 \$1	2294		ADDI	\$1 -1
2229		ADDI	\$1 1	2295		EXCH	\$10 \$1
2230		EXCH	\$12 \$1	2296		ADDI	\$1 -1
2231	obj_con_62_i:	ADDI	\$12 -8	2297		EXCH	\$9 \$1
2232		ADDI	\$1 1	2298		ADDI	\$1 -1
2233		EXCH	\$6 \$1	2299		EXCH	\$8 \$1
2234		ADDI	\$1 1	2300		ADDI	\$1 -1
2235		EXCH	\$7 \$1	2301		EXCH	\$7 \$1
2236		ADDI	\$1 1	2302		ADDI	\$1 -1
2237		EXCH	\$8 \$1	2303		EXCH	\$6 \$1
2238		ADDI	\$1 1	2304		ADDI	\$1 -1
2239		EXCH	\$9 \$1	2305	obj_con_64:	ADDI	\$12 8
2240		ADDI	\$1 1	2306		EXCH	\$12 \$1
2241		EXCH	\$10 \$1	2307		ADDI	\$1 -1
2242		ADDI	\$1 1	2308		EXCH	\$11 \$1
2243		EXCH	\$3 \$1	2309		ADDI	\$1 -1
2244		XORI	\$12 10	2310		BRA	l_malloc
2245		EXCH	\$12 \$11	2311		ADDI	\$1 1
2246		ADDI	\$11 1	2312		EXCH	\$11 \$1
2247		XORI	\$12 1	2313		ADDI	\$1 1
2248		EXCH	\$12 \$11	2314		EXCH	\$12 \$1
2249	obj_con_62_bot:	ADDI	\$11 -1	2315	obj_con_64_i:	ADDI	\$12 -8
2250		EXCH	\$11 \$6	2316		ADDI	\$1 1
2251		EXCH	\$3 \$1	2317		EXCH	\$6 \$1
2252		ADDI	\$1 -1	2318		ADDI	\$1 1
2253		EXCH	\$10 \$1	2319		EXCH	\$7 \$1
2254		ADDI	\$1 -1	2320		ADDI	\$1 1
2255		EXCH	\$9 \$1	2321		EXCH	\$8 \$1
2256		ADDI	\$1 -1	2322		ADDI	\$1 1
2257		EXCH	\$8 \$1	2323		EXCH	\$9 \$1
2258		ADDI	\$1 -1	2324		ADDI	\$1 1
2259		EXCH	\$7 \$1	2325		EXCH	\$10 \$1
2260		ADDI	\$1 -1	2326		ADDI	\$1 1
2261		EXCH	\$6 \$1	2327		EXCH	\$3 \$1
2262		ADDI	\$1 -1	2328		XORI	\$12 10
2263	obj_con_63:	ADDI	\$12 8	2329		EXCH	\$12 \$11
2264		EXCH	\$12 \$1	2330		ADDI	\$11 1
2265		ADDI	\$1 -1	2331		XORI	\$12 1
2266		EXCH	\$11 \$1	2332		EXCH	\$12 \$11
2267		ADDI	\$1 -1	2333	obj_con_64_bot:	ADDI	\$11 -1
2268		BRA	l_malloc	2334		EXCH	\$11 \$8
2269		ADDI	\$1 1	2335		EXCH	\$3 \$1

2336		ADDI	\$1 -1	2402		ADDI	\$1 1
2337		EXCH	\$10 \$1	2403		EXCH	\$7 \$1
2338		ADDI	\$1 -1	2404		ADDI	\$1 1
2339		EXCH	\$9 \$1	2405		EXCH	\$8 \$1
2340		ADDI	\$1 -1	2406		ADDI	\$1 1
2341		EXCH	\$8 \$1	2407		EXCH	\$9 \$1
2342		ADDI	\$1 -1	2408		ADDI	\$1 1
2343		EXCH	\$7 \$1	2409		EXCH	\$10 \$1
2344		ADDI	\$1 -1	2410		ADDI	\$1 1
2345		EXCH	\$6 \$1	2411		EXCH	\$3 \$1
2346		ADDI	\$1 -1	2412		XORI	\$12 10
2347	obj_con_65:	ADDI	\$12 8	2413		EXCH	\$12 \$11
2348		EXCH	\$12 \$1	2414		ADDI	\$11 1
2349		ADDI	\$1 -1	2415		XORI	\$12 1
2350		EXCH	\$11 \$1	2416		EXCH	\$12 \$11
2351		ADDI	\$1 -1	2417	obj_con_66_bot:	ADDI	\$11 -1
2352		BRA	l_malloc	2418		EXCH	\$11 \$10
2353		ADDI	\$1 1	2419		ADD	\$11 \$3
2354		EXCH	\$11 \$1	2420		ADDI	\$11 14
2355		ADDI	\$1 1	2421		EXCH	\$12 \$11
2356		EXCH	\$12 \$1	2422		ADDI	\$11 -14
2357	obj_con_65_i:	ADDI	\$12 -8	2423		SUB	\$11 \$3
2358		ADDI	\$1 1	2424		ADD	\$13 \$3
2359		EXCH	\$6 \$1	2425		ADDI	\$13 10
2360		ADDI	\$1 1	2426		EXCH	\$14 \$13
2361		EXCH	\$7 \$1	2427		ADDI	\$13 -10
2362		ADDI	\$1 1	2428		SUB	\$13 \$3
2363		EXCH	\$8 \$1	2429		ADD	\$12 \$14
2364		ADDI	\$1 1	2430		ADD	\$13 \$3
2365		EXCH	\$9 \$1	2431		ADDI	\$13 10
2366		ADDI	\$1 1	2432		EXCH	\$14 \$13
2367		EXCH	\$10 \$1	2433		ADDI	\$13 -10
2368		ADDI	\$1 1	2434		SUB	\$13 \$3
2369		EXCH	\$3 \$1	2435		ADD	\$11 \$3
2370		XORI	\$12 10	2436		ADDI	\$11 14
2371		EXCH	\$12 \$11	2437		EXCH	\$12 \$11
2372		ADDI	\$11 1	2438		ADDI	\$11 -14
2373		XORI	\$12 1	2439		SUB	\$11 \$3
2374		EXCH	\$12 \$11	2440		EXCH	\$11 \$6
2375	obj_con_65_bot:	ADDI	\$11 -1	2441		XOR	\$12 \$11
2376		EXCH	\$11 \$9	2442	loadMetAdd_67:	EXCH	\$13 \$12
2377		EXCH	\$3 \$1	2443		ADDI	\$13 3
2378		ADDI	\$1 -1	2444		EXCH	\$14 \$13
2379		EXCH	\$10 \$1	2445		XOR	\$15 \$14
2380		ADDI	\$1 -1	2446		EXCH	\$14 \$13
2381		EXCH	\$9 \$1	2447		ADDI	\$13 -3
2382		ADDI	\$1 -1	2448		EXCH	\$13 \$12
2383		EXCH	\$8 \$1	2449		EXCH	\$11 \$6
2384		ADDI	\$1 -1	2450		ADD	\$16 \$3
2385		EXCH	\$7 \$1	2451		ADDI	\$16 14
2386		ADDI	\$1 -1	2452		EXCH	\$3 \$1
2387		EXCH	\$6 \$1	2453		ADDI	\$1 -1
2388		ADDI	\$1 -1	2454		EXCH	\$10 \$1
2389	obj_con_66:	ADDI	\$12 8	2455		ADDI	\$1 -1
2390		EXCH	\$12 \$1	2456		EXCH	\$9 \$1
2391		ADDI	\$1 -1	2457		ADDI	\$1 -1
2392		EXCH	\$11 \$1	2458		EXCH	\$8 \$1
2393		ADDI	\$1 -1	2459		ADDI	\$1 -1
2394		BRA	l_malloc	2460		EXCH	\$7 \$1
2395		ADDI	\$1 1	2461		ADDI	\$1 -1
2396		EXCH	\$11 \$1	2462		EXCH	\$6 \$1
2397		ADDI	\$1 1	2463		ADDI	\$1 -1
2398		EXCH	\$12 \$1	2464		EXCH	\$16 \$1
2399	obj_con_66_i:	ADDI	\$12 -8	2465		ADDI	\$1 -1
2400		ADDI	\$1 1	2466		EXCH	\$12 \$1
2401		EXCH	\$6 \$1	2467		ADDI	\$1 -1

2468		ADDI	\$15 -2468	2534		ADDI	\$1 -1
2469	l_rjmp_top_69:	RBRA	l_rjmp_bot_70	2535		EXCH	\$7 \$1
2470	l_jmp_68:	SWAPBR	\$15	2536		ADDI	\$1 -1
2471		NEG	\$15	2537		EXCH	\$6 \$1
2472	l_rjmp_bot_70:	BRA	l_rjmp_top_69	2538		ADDI	\$1 -1
2473		ADDI	\$15 2468	2539		EXCH	\$16 \$1
2474		ADDI	\$1 1	2540		ADDI	\$1 -1
2475		EXCH	\$12 \$1	2541		EXCH	\$12 \$1
2476		ADDI	\$1 1	2542		ADDI	\$1 -1
2477		EXCH	\$16 \$1	2543		ADDI	\$15 -2543
2478		ADDI	\$1 1	2544	l_rjmp_top_73:	RBRA	l_rjmp_bot_74
2479		EXCH	\$6 \$1	2545	l_jmp_72:	SWAPBR	\$15
2480		ADDI	\$1 1	2546		NEG	\$15
2481		EXCH	\$7 \$1	2547	l_rjmp_bot_74:	BRA	l_rjmp_top_73
2482		ADDI	\$1 1	2548		ADDI	\$15 2543
2483		EXCH	\$8 \$1	2549		ADDI	\$1 1
2484		ADDI	\$1 1	2550		EXCH	\$12 \$1
2485		EXCH	\$9 \$1	2551		ADDI	\$1 1
2486		ADDI	\$1 1	2552		EXCH	\$16 \$1
2487		EXCH	\$10 \$1	2553		ADDI	\$1 1
2488		ADDI	\$1 1	2554		EXCH	\$6 \$1
2489		EXCH	\$3 \$1	2555		ADDI	\$1 1
2490		ADDI	\$16 -14	2556		EXCH	\$7 \$1
2491		SUB	\$16 \$3	2557		ADDI	\$1 1
2492		EXCH	\$11 \$6	2558		EXCH	\$8 \$1
2493		EXCH	\$13 \$12	2559		ADDI	\$1 1
2494		ADDI	\$13 3	2560		EXCH	\$9 \$1
2495		EXCH	\$14 \$13	2561		ADDI	\$1 1
2496		XOR	\$15 \$14	2562		EXCH	\$10 \$1
2497		EXCH	\$14 \$13	2563		ADDI	\$1 1
2498		ADDI	\$13 -3	2564		EXCH	\$3 \$1
2499	loadMetAdd_67_i:	EXCH	\$13 \$12	2565		ADDI	\$16 -14
2500		XOR	\$12 \$11	2566		SUB	\$16 \$3
2501		EXCH	\$11 \$6	2567		EXCH	\$11 \$7
2502		ADD	\$11 \$3	2568		EXCH	\$13 \$12
2503		ADDI	\$11 14	2569		ADDI	\$13 3
2504		EXCH	\$12 \$11	2570		EXCH	\$14 \$13
2505		ADDI	\$11 -14	2571		XOR	\$15 \$14
2506		SUB	\$11 \$3	2572		EXCH	\$14 \$13
2507		XORI	\$13 1	2573		ADDI	\$13 -3
2508		ADD	\$12 \$13	2574	loadMetAdd_71_i:	EXCH	\$13 \$12
2509		XORI	\$13 1	2575		XOR	\$12 \$11
2510		ADD	\$11 \$3	2576		EXCH	\$11 \$7
2511		ADDI	\$11 14	2577		ADD	\$11 \$3
2512		EXCH	\$12 \$11	2578		ADDI	\$11 14
2513		ADDI	\$11 -14	2579		EXCH	\$12 \$11
2514		SUB	\$11 \$3	2580		ADDI	\$11 -14
2515		EXCH	\$11 \$7	2581		SUB	\$11 \$3
2516		XOR	\$12 \$11	2582		XORI	\$13 1
2517	loadMetAdd_71:	EXCH	\$13 \$12	2583		ADD	\$12 \$13
2518		ADDI	\$13 3	2584		XORI	\$13 1
2519		EXCH	\$14 \$13	2585		ADD	\$11 \$3
2520		XOR	\$15 \$14	2586		ADDI	\$11 14
2521		EXCH	\$14 \$13	2587		EXCH	\$12 \$11
2522		ADDI	\$13 -3	2588		ADDI	\$11 -14
2523		EXCH	\$13 \$12	2589		SUB	\$11 \$3
2524		EXCH	\$11 \$7	2590		EXCH	\$11 \$8
2525		ADD	\$16 \$3	2591		XOR	\$12 \$11
2526		ADDI	\$16 14	2592	loadMetAdd_75:	EXCH	\$13 \$12
2527		EXCH	\$3 \$1	2593		ADDI	\$13 3
2528		ADDI	\$1 -1	2594		EXCH	\$14 \$13
2529		EXCH	\$10 \$1	2595		XOR	\$15 \$14
2530		ADDI	\$1 -1	2596		EXCH	\$14 \$13
2531		EXCH	\$9 \$1	2597		ADDI	\$13 -3
2532		ADDI	\$1 -1	2598		EXCH	\$13 \$12
2533		EXCH	\$8 \$1	2599		EXCH	\$11 \$8

2600		ADD	\$16 \$3	2666		XOR	\$12 \$11
2601		ADDI	\$16 14	2667	loadMetAdd_79:	EXCH	\$13 \$12
2602		EXCH	\$3 \$1	2668		ADDI	\$13 3
2603		ADDI	\$1 -1	2669		EXCH	\$14 \$13
2604		EXCH	\$10 \$1	2670		XOR	\$15 \$14
2605		ADDI	\$1 -1	2671		EXCH	\$14 \$13
2606		EXCH	\$9 \$1	2672		ADDI	\$13 -3
2607		ADDI	\$1 -1	2673		EXCH	\$13 \$12
2608		EXCH	\$8 \$1	2674		EXCH	\$11 \$10
2609		ADDI	\$1 -1	2675		ADD	\$16 \$3
2610		EXCH	\$7 \$1	2676		ADDI	\$16 14
2611		ADDI	\$1 -1	2677		EXCH	\$3 \$1
2612		EXCH	\$6 \$1	2678		ADDI	\$1 -1
2613		ADDI	\$1 -1	2679		EXCH	\$10 \$1
2614		EXCH	\$16 \$1	2680		ADDI	\$1 -1
2615		ADDI	\$1 -1	2681		EXCH	\$9 \$1
2616		EXCH	\$12 \$1	2682		ADDI	\$1 -1
2617		ADDI	\$1 -1	2683		EXCH	\$8 \$1
2618		ADDI	\$15 -2618	2684		ADDI	\$1 -1
2619	l_rjmp_top_77:	RBRA	l_rjmp_bot_78	2685		EXCH	\$7 \$1
2620	l_jmp_76:	SWAPBR	\$15	2686		ADDI	\$1 -1
2621		NEG	\$15	2687		EXCH	\$6 \$1
2622	l_rjmp_bot_78:	BRA	l_rjmp_top_78	2688		ADDI	\$1 -1
2623		ADDI	\$15 2618	2689		EXCH	\$16 \$1
2624		ADDI	\$1 1	2690		ADDI	\$1 -1
2625		EXCH	\$12 \$1	2691		EXCH	\$12 \$1
2626		ADDI	\$1 1	2692		ADDI	\$1 -1
2627		EXCH	\$16 \$1	2693		ADDI	\$15 -2693
2628		ADDI	\$1 1	2694	l_rjmp_top_81:	RBRA	l_rjmp_bot_82
2629		EXCH	\$6 \$1	2695	l_jmp_80:	SWAPBR	\$15
2630		ADDI	\$1 1	2696		NEG	\$15
2631		EXCH	\$7 \$1	2697	l_rjmp_bot_82:	BRA	l_rjmp_top_81
2632		ADDI	\$1 1	2698		ADDI	\$15 2693
2633		EXCH	\$8 \$1	2699		ADDI	\$1 1
2634		ADDI	\$1 1	2700		EXCH	\$12 \$1
2635		EXCH	\$9 \$1	2701		ADDI	\$1 1
2636		ADDI	\$1 1	2702		EXCH	\$16 \$1
2637		EXCH	\$10 \$1	2703		ADDI	\$1 1
2638		ADDI	\$1 1	2704		EXCH	\$6 \$1
2639		EXCH	\$3 \$1	2705		ADDI	\$1 1
2640		ADDI	\$16 -14	2706		EXCH	\$7 \$1
2641		SUB	\$16 \$3	2707		ADDI	\$1 1
2642		EXCH	\$11 \$8	2708		EXCH	\$8 \$1
2643		EXCH	\$13 \$12	2709		ADDI	\$1 1
2644		ADDI	\$13 3	2710		EXCH	\$9 \$1
2645		EXCH	\$14 \$13	2711		ADDI	\$1 1
2646		XOR	\$15 \$14	2712		EXCH	\$10 \$1
2647		EXCH	\$14 \$13	2713		ADDI	\$1 1
2648		ADDI	\$13 -3	2714		EXCH	\$3 \$1
2649	loadMetAdd_75_i:	EXCH	\$13 \$12	2715		ADDI	\$16 -14
2650		XOR	\$12 \$11	2716		SUB	\$16 \$3
2651		EXCH	\$11 \$8	2717		EXCH	\$11 \$10
2652		ADD	\$11 \$3	2718		EXCH	\$13 \$12
2653		ADDI	\$11 14	2719		ADDI	\$13 3
2654		EXCH	\$12 \$11	2720		EXCH	\$14 \$13
2655		ADDI	\$11 -14	2721		XOR	\$15 \$14
2656		SUB	\$11 \$3	2722		EXCH	\$14 \$13
2657		XORI	\$13 1	2723		ADDI	\$13 -3
2658		ADD	\$12 \$13	2724	loadMetAdd_79_i:	EXCH	\$13 \$12
2659		XORI	\$13 1	2725		XOR	\$12 \$11
2660		ADD	\$11 \$3	2726		EXCH	\$11 \$10
2661		ADDI	\$11 14	2727		ADD	\$11 \$3
2662		EXCH	\$12 \$11	2728		ADDI	\$11 2
2663		ADDI	\$11 -14	2729		EXCH	\$12 \$11
2664		SUB	\$11 \$3	2730		ADDI	\$11 -2
2665		EXCH	\$11 \$10	2731		SUB	\$11 \$3

2732		EXCH	\$13 \$6	2798		ADDI	\$1 1
2733	swap_83:	XOR	\$12 \$13	2799		EXCH	\$13 \$1
2734		XOR	\$13 \$12	2800		ADDI	\$1 1
2735		XOR	\$12 \$13	2801		EXCH	\$6 \$1
2736		EXCH	\$13 \$6	2802		ADDI	\$1 1
2737		ADD	\$11 \$3	2803		EXCH	\$7 \$1
2738		ADDI	\$11 2	2804		ADDI	\$1 1
2739		EXCH	\$12 \$11	2805		EXCH	\$8 \$1
2740		ADDI	\$11 -2	2806		ADDI	\$1 1
2741		SUB	\$11 \$3	2807		EXCH	\$9 \$1
2742		EXCH	\$11 \$6	2808		ADDI	\$1 1
2743		ADD	\$12 \$3	2809		EXCH	\$10 \$1
2744		ADDI	\$12 2	2810		ADDI	\$1 1
2745		EXCH	\$13 \$12	2811		EXCH	\$3 \$1
2746		ADDI	\$12 -2	2812		ADD	\$11 \$3
2747		SUB	\$12 \$3	2813		ADDI	\$11 2
2748	copy_84:	XOR	\$11 \$13	2814		EXCH	\$12 \$11
2749		ADDI	\$13 1	2815		ADDI	\$11 -2
2750		EXCH	\$14 \$13	2816		SUB	\$11 \$3
2751		ADDI	\$14 1	2817		EXCH	\$14 \$13
2752		EXCH	\$14 \$13	2818		ADDI	\$14 2
2753		ADDI	\$13 -1	2819		EXCH	\$15 \$14
2754		ADD	\$12 \$3	2820		XOR	\$16 \$15
2755		ADDI	\$12 2	2821		EXCH	\$15 \$14
2756		EXCH	\$13 \$12	2822		ADDI	\$14 -2
2757		ADDI	\$12 -2	2823	loadMetAdd_85_i:	EXCH	\$14 \$13
2758		SUB	\$12 \$3	2824		XOR	\$13 \$12
2759		EXCH	\$11 \$6	2825		ADD	\$11 \$3
2760		ADD	\$11 \$3	2826		ADDI	\$11 2
2761		ADDI	\$11 2	2827		EXCH	\$12 \$11
2762		EXCH	\$12 \$11	2828		ADDI	\$11 -2
2763		ADDI	\$11 -2	2829		SUB	\$11 \$3
2764		SUB	\$11 \$3	2830		EXCH	\$11 \$6
2765		XOR	\$13 \$12	2831		EXCH	\$12 \$7
2766	loadMetAdd_85:	EXCH	\$14 \$13	2832	copy_89:	XOR	\$11 \$12
2767		ADDI	\$14 2	2833		ADDI	\$12 1
2768		EXCH	\$15 \$14	2834		EXCH	\$13 \$12
2769		XOR	\$16 \$15	2835		ADDI	\$13 1
2770		EXCH	\$15 \$14	2836		EXCH	\$13 \$12
2771		ADDI	\$14 -2	2837		ADDI	\$12 -1
2772		EXCH	\$14 \$13	2838		EXCH	\$12 \$7
2773		ADD	\$11 \$3	2839		EXCH	\$11 \$6
2774		ADDI	\$11 2	2840		EXCH	\$11 \$7
2775		EXCH	\$12 \$11	2841		XOR	\$12 \$11
2776		ADDI	\$11 -2	2842	loadMetAdd_90:	EXCH	\$13 \$12
2777		SUB	\$11 \$3	2843		ADDI	\$13 2
2778		EXCH	\$3 \$1	2844		EXCH	\$14 \$13
2779		ADDI	\$1 -1	2845		XOR	\$15 \$14
2780		EXCH	\$10 \$1	2846		EXCH	\$14 \$13
2781		ADDI	\$1 -1	2847		ADDI	\$13 -2
2782		EXCH	\$9 \$1	2848		EXCH	\$13 \$12
2783		ADDI	\$1 -1	2849		EXCH	\$11 \$7
2784		EXCH	\$8 \$1	2850		EXCH	\$3 \$1
2785		ADDI	\$1 -1	2851		ADDI	\$1 -1
2786		EXCH	\$7 \$1	2852		EXCH	\$10 \$1
2787		ADDI	\$1 -1	2853		ADDI	\$1 -1
2788		EXCH	\$6 \$1	2854		EXCH	\$9 \$1
2789		ADDI	\$1 -1	2855		ADDI	\$1 -1
2790		EXCH	\$13 \$1	2856		EXCH	\$8 \$1
2791		ADDI	\$1 -1	2857		ADDI	\$1 -1
2792		ADDI	\$16 -2792	2858		EXCH	\$7 \$1
2793	l_rjmp_top_87:	RBRA	l_rjmp_bot_88	2859		ADDI	\$1 -1
2794	l_rjmp_86:	SWAPBR	\$16	2860		EXCH	\$6 \$1
2795		NEG	\$16	2861		ADDI	\$1 -1
2796	l_rjmp_bot_88:	BRA	l_rjmp_top_87	2862		EXCH	\$12 \$1
2797		ADDI	\$16 2792	2863		ADDI	\$1 -1

2864		ADDI	\$15 -2864	2930	l_rjmp_96:	SWAPBR	\$15
2865	l_rjmp_top_92:	RBRA	l_rjmp_bot_93	2931		NEG	\$15
2866	l_rjmp_91:	SWAPBR	\$15	2932	l_rjmp_bot_98:	BRA	l_rjmp_top_97
2867		NEG	\$15	2933		ADDI	\$15 2928
2868	l_rjmp_bot_93:	BRA	l_rjmp_top_93	2934		ADDI	\$1 1
2869		ADDI	\$15 2864	2935		EXCH	\$12 \$1
2870		ADDI	\$1 1	2936		ADDI	\$1 1
2871		EXCH	\$12 \$1	2937		EXCH	\$6 \$1
2872		ADDI	\$1 1	2938		ADDI	\$1 1
2873		EXCH	\$6 \$1	2939		EXCH	\$7 \$1
2874		ADDI	\$1 1	2940		ADDI	\$1 1
2875		EXCH	\$7 \$1	2941		EXCH	\$8 \$1
2876		ADDI	\$1 1	2942		ADDI	\$1 1
2877		EXCH	\$8 \$1	2943		EXCH	\$9 \$1
2878		ADDI	\$1 1	2944		ADDI	\$1 1
2879		EXCH	\$9 \$1	2945		EXCH	\$10 \$1
2880		ADDI	\$1 1	2946		ADDI	\$1 1
2881		EXCH	\$10 \$1	2947		EXCH	\$3 \$1
2882		ADDI	\$1 1	2948		EXCH	\$11 \$8
2883		EXCH	\$3 \$1	2949		EXCH	\$13 \$12
2884		EXCH	\$11 \$7	2950		ADDI	\$13 2
2885		EXCH	\$13 \$12	2951		EXCH	\$14 \$13
2886		ADDI	\$13 2	2952		XOR	\$15 \$14
2887		EXCH	\$14 \$13	2953		EXCH	\$14 \$13
2888		XOR	\$15 \$14	2954		ADDI	\$13 -2
2889		EXCH	\$14 \$13	2955	loadMetAdd_95_i:	EXCH	\$13 \$12
2890		ADDI	\$13 -2	2956		XOR	\$12 \$11
2891	loadMetAdd_90_i:	EXCH	\$13 \$12	2957		EXCH	\$11 \$8
2892		XOR	\$12 \$11	2958		EXCH	\$11 \$6
2893		EXCH	\$11 \$7	2959		EXCH	\$12 \$9
2894		EXCH	\$11 \$6	2960	copy_99:	XOR	\$11 \$12
2895		EXCH	\$12 \$8	2961		ADDI	\$12 1
2896	copy_94:	XOR	\$11 \$12	2962		EXCH	\$13 \$12
2897		ADDI	\$12 1	2963		ADDI	\$13 1
2898		EXCH	\$13 \$12	2964		EXCH	\$13 \$12
2899		ADDI	\$13 1	2965		ADDI	\$12 -1
2900		EXCH	\$13 \$12	2966		EXCH	\$12 \$9
2901		ADDI	\$12 -1	2967		EXCH	\$11 \$6
2902		EXCH	\$12 \$8	2968		EXCH	\$11 \$9
2903		EXCH	\$11 \$6	2969		XOR	\$12 \$11
2904		EXCH	\$11 \$8	2970	loadMetAdd_100:	EXCH	\$13 \$12
2905		XOR	\$12 \$11	2971		ADDI	\$13 2
2906	loadMetAdd_95:	EXCH	\$13 \$12	2972		EXCH	\$14 \$13
2907		ADDI	\$13 2	2973		XOR	\$15 \$14
2908		EXCH	\$14 \$13	2974		EXCH	\$14 \$13
2909		XOR	\$15 \$14	2975		ADDI	\$13 -2
2910		EXCH	\$14 \$13	2976		EXCH	\$13 \$12
2911		ADDI	\$13 -2	2977		EXCH	\$11 \$9
2912		EXCH	\$13 \$12	2978		EXCH	\$3 \$1
2913		EXCH	\$11 \$8	2979		ADDI	\$1 -1
2914		EXCH	\$3 \$1	2980		EXCH	\$10 \$1
2915		ADDI	\$1 -1	2981		ADDI	\$1 -1
2916		EXCH	\$10 \$1	2982		EXCH	\$9 \$1
2917		ADDI	\$1 -1	2983		ADDI	\$1 -1
2918		EXCH	\$9 \$1	2984		EXCH	\$8 \$1
2919		ADDI	\$1 -1	2985		ADDI	\$1 -1
2920		EXCH	\$8 \$1	2986		EXCH	\$7 \$1
2921		ADDI	\$1 -1	2987		ADDI	\$1 -1
2922		EXCH	\$7 \$1	2988		EXCH	\$6 \$1
2923		ADDI	\$1 -1	2989		ADDI	\$1 -1
2924		EXCH	\$6 \$1	2990		EXCH	\$12 \$1
2925		ADDI	\$1 -1	2991		ADDI	\$1 -1
2926		EXCH	\$12 \$1	2992		ADDI	\$15 -2992
2927		ADDI	\$1 -1	2993	l_rjmp_top_102:	RBRA	l_rjmp_bot_103
2928		ADDI	\$15 -2928	2994	l_rjmp_101:	SWAPBR	\$15
2929	l_rjmp_top_97:	RBRA	l_rjmp_bot_98	2995		NEG	\$15

2996	l_rjmp_bot_103:	BRA	l_rjmp_top_100	3062	ADDI	\$1 1
2997		ADDI	\$15 2992	3063	EXCH	\$12 \$1
2998		ADDI	\$1 1	3064	ADDI	\$1 1
2999		EXCH	\$12 \$1	3065	EXCH	\$6 \$1
3000		ADDI	\$1 1	3066	ADDI	\$1 1
3001		EXCH	\$6 \$1	3067	EXCH	\$7 \$1
3002		ADDI	\$1 1	3068	ADDI	\$1 1
3003		EXCH	\$7 \$1	3069	EXCH	\$8 \$1
3004		ADDI	\$1 1	3070	ADDI	\$1 1
3005		EXCH	\$8 \$1	3071	EXCH	\$9 \$1
3006		ADDI	\$1 1	3072	ADDI	\$1 1
3007		EXCH	\$9 \$1	3073	EXCH	\$10 \$1
3008		ADDI	\$1 1	3074	ADDI	\$1 1
3009		EXCH	\$10 \$1	3075	EXCH	\$3 \$1
3010		ADDI	\$1 1	3076	EXCH	\$11 \$10
3011		EXCH	\$3 \$1	3077	EXCH	\$13 \$12
3012		EXCH	\$11 \$9	3078	ADDI	\$13 2
3013		EXCH	\$13 \$12	3079	EXCH	\$14 \$13
3014		ADDI	\$13 2	3080	XOR	\$15 \$14
3015		EXCH	\$14 \$13	3081	EXCH	\$14 \$13
3016		XOR	\$15 \$14	3082	ADDI	\$13 -2
3017		EXCH	\$14 \$13	3083	EXCH	\$13 \$12
3018		ADDI	\$13 -2	3084	XOR	\$12 \$11
3019	loadMetAdd_100_i:	EXCH	\$13 \$12	3085	EXCH	\$11 \$10
3020		XOR	\$12 \$11	3086	EXCH	\$11 \$6
3021		EXCH	\$11 \$9	3087	EXCH	\$12 \$9
3022		EXCH	\$11 \$6	3088	XOR	\$11 \$12
3023		EXCH	\$12 \$10	3089	ADDI	\$12 1
3024	copy_104:	XOR	\$11 \$12	3090	EXCH	\$13 \$12
3025		ADDI	\$12 1	3091	ADDI	\$13 1
3026		EXCH	\$13 \$12	3092	EXCH	\$13 \$12
3027		ADDI	\$13 1	3093	ADDI	\$12 -1
3028		EXCH	\$13 \$12	3094	EXCH	\$12 \$9
3029		ADDI	\$12 -1	3095	EXCH	\$11 \$6
3030		EXCH	\$12 \$10	3096	EXCH	\$11 \$10
3031		EXCH	\$11 \$6	3097	XOR	\$12 \$11
3032		EXCH	\$11 \$10	3098	EXCH	\$13 \$12
3033		XOR	\$12 \$11	3099	ADDI	\$13 0
3034	loadMetAdd_105:	EXCH	\$13 \$12	3100	EXCH	\$14 \$13
3035		ADDI	\$13 2	3101	XOR	\$15 \$14
3036		EXCH	\$14 \$13	3102	EXCH	\$14 \$13
3037		XOR	\$15 \$14	3103	ADDI	\$13 0
3038		EXCH	\$14 \$13	3104	EXCH	\$13 \$12
3039		ADDI	\$13 -2	3105	EXCH	\$11 \$10
3040		EXCH	\$13 \$12	3106	EXCH	\$3 \$1
3041		EXCH	\$11 \$10	3107	ADDI	\$1 -1
3042		EXCH	\$3 \$1	3108	EXCH	\$10 \$1
3043		ADDI	\$1 -1	3109	ADDI	\$1 -1
3044		EXCH	\$10 \$1	3110	EXCH	\$9 \$1
3045		ADDI	\$1 -1	3111	ADDI	\$1 -1
3046		EXCH	\$9 \$1	3112	EXCH	\$8 \$1
3047		ADDI	\$1 -1	3113	ADDI	\$1 -1
3048		EXCH	\$8 \$1	3114	EXCH	\$7 \$1
3049		ADDI	\$1 -1	3115	ADDI	\$1 -1
3050		EXCH	\$7 \$1	3116	EXCH	\$6 \$1
3051		ADDI	\$1 -1	3117	ADDI	\$1 -1
3052		EXCH	\$6 \$1	3118	EXCH	\$12 \$1
3053		ADDI	\$1 -1	3119	ADDI	\$1 -1
3054		EXCH	\$12 \$1	3120	ADDI	\$15 -3120
3055		ADDI	\$1 -1	3121	l_rjmp_top_112:	RBRA l_rjmp_bot_113
3056		ADDI	\$15 -3056	3122	l_jmp_111:	SWAPBR \$15
3057	l_rjmp_top_107:	RBRA	l_rjmp_bot_100	3123		NEG \$15
3058	l_jmp_106:	SWAPBR	\$15	3124	l_rjmp_bot_113:	BRA l_rjmp_top_112
3059		NEG	\$15	3125		ADDI \$15 3120
3060	l_rjmp_bot_108:	BRA	l_rjmp_top_100	3126		ADDI \$1 1
3061		ADDI	\$15 3056	3127		EXCH \$12 \$1

3128		ADDI	\$1 1	3194		EXCH	\$11 \$9
3129		EXCH	\$6 \$1	3195		EXCH	\$13 \$12
3130		ADDI	\$1 1	3196		ADDI	\$13 1
3131		EXCH	\$7 \$1	3197		EXCH	\$14 \$13
3132		ADDI	\$1 1	3198		XOR	\$15 \$14
3133		EXCH	\$8 \$1	3199		EXCH	\$14 \$13
3134		ADDI	\$1 1	3200		ADDI	\$13 -1
3135		EXCH	\$9 \$1	3201	loadMetAdd_114_i:	EXCH	\$13 \$12
3136		ADDI	\$1 1	3202		XOR	\$12 \$11
3137		EXCH	\$10 \$1	3203		EXCH	\$11 \$9
3138		ADDI	\$1 1	3204		EXCH	\$11 \$6
3139		EXCH	\$3 \$1	3205		EXCH	\$12 \$8
3140		EXCH	\$11 \$10	3206	copy_118:	XOR	\$11 \$12
3141		EXCH	\$13 \$12	3207		ADDI	\$12 1
3142		ADDI	\$13 0	3208		EXCH	\$13 \$12
3143		EXCH	\$14 \$13	3209		ADDI	\$13 1
3144		XOR	\$15 \$14	3210		EXCH	\$13 \$12
3145		EXCH	\$14 \$13	3211		ADDI	\$12 -1
3146		ADDI	\$13 0	3212		EXCH	\$12 \$8
3147	loadMetAdd_110_i:	EXCH	\$13 \$12	3213		EXCH	\$11 \$6
3148		XOR	\$12 \$11	3214		EXCH	\$11 \$9
3149		EXCH	\$11 \$10	3215		XOR	\$12 \$11
3150		EXCH	\$11 \$9	3216	loadMetAdd_119:	EXCH	\$13 \$12
3151		XOR	\$12 \$11	3217		ADDI	\$13 0
3152	loadMetAdd_114:	EXCH	\$13 \$12	3218		EXCH	\$14 \$13
3153		ADDI	\$13 1	3219		XOR	\$15 \$14
3154		EXCH	\$14 \$13	3220		EXCH	\$14 \$13
3155		XOR	\$15 \$14	3221		ADDI	\$13 0
3156		EXCH	\$14 \$13	3222		EXCH	\$13 \$12
3157		ADDI	\$13 -1	3223		EXCH	\$11 \$9
3158		EXCH	\$13 \$12	3224		EXCH	\$3 \$1
3159		EXCH	\$11 \$9	3225		ADDI	\$1 -1
3160		EXCH	\$3 \$1	3226		EXCH	\$10 \$1
3161		ADDI	\$1 -1	3227		ADDI	\$1 -1
3162		EXCH	\$9 \$1	3228		EXCH	\$9 \$1
3163		ADDI	\$1 -1	3229		ADDI	\$1 -1
3164		EXCH	\$8 \$1	3230		EXCH	\$8 \$1
3165		ADDI	\$1 -1	3231		ADDI	\$1 -1
3166		EXCH	\$7 \$1	3232		EXCH	\$7 \$1
3167		ADDI	\$1 -1	3233		ADDI	\$1 -1
3168		EXCH	\$6 \$1	3234		EXCH	\$6 \$1
3169		ADDI	\$1 -1	3235		ADDI	\$1 -1
3170		EXCH	\$10 \$1	3236		EXCH	\$12 \$1
3171		ADDI	\$1 -1	3237		ADDI	\$1 -1
3172		EXCH	\$12 \$1	3238		ADDI	\$15 -3238
3173		ADDI	\$1 -1	3239	l_rjmp_top_121:	RBRA	l_rjmp_bot_122
3174		ADDI	\$15 -3174	3240	l_jmp_120:	SWAPBR	\$15
3175	l_rjmp_top_116:	RBRA	l_rjmp_bot_117	3241		NEG	\$15
3176	l_jmp_115:	SWAPBR	\$15	3242	l_rjmp_bot_122:	BRA	l_rjmp_top_121
3177		NEG	\$15	3243		ADDI	\$15 3238
3178	l_rjmp_bot_117:	BRA	l_rjmp_top_116	3244		ADDI	\$1 1
3179		ADDI	\$15 3174	3245		EXCH	\$12 \$1
3180		ADDI	\$1 1	3246		ADDI	\$1 1
3181		EXCH	\$12 \$1	3247		EXCH	\$6 \$1
3182		ADDI	\$1 1	3248		ADDI	\$1 1
3183		EXCH	\$10 \$1	3249		EXCH	\$7 \$1
3184		ADDI	\$1 1	3250		ADDI	\$1 1
3185		EXCH	\$6 \$1	3251		EXCH	\$8 \$1
3186		ADDI	\$1 1	3252		ADDI	\$1 1
3187		EXCH	\$7 \$1	3253		EXCH	\$9 \$1
3188		ADDI	\$1 1	3254		ADDI	\$1 1
3189		EXCH	\$8 \$1	3255		EXCH	\$10 \$1
3190		ADDI	\$1 1	3256		ADDI	\$1 1
3191		EXCH	\$9 \$1	3257		EXCH	\$3 \$1
3192		ADDI	\$1 1	3258		EXCH	\$11 \$9
3193		EXCH	\$3 \$1	3259		EXCH	\$13 \$12

3260		ADDI	\$13 0	3326		EXCH	\$13 \$12
3261		EXCH	\$14 \$13	3327		ADDI	\$13 1
3262		XOR	\$15 \$14	3328		EXCH	\$13 \$12
3263		EXCH	\$14 \$13	3329		ADDI	\$12 -1
3264		ADDI	\$13 0	3330		EXCH	\$12 \$7
3265	loadMetAdd_119_i:	EXCH	\$13 \$12	3331		EXCH	\$11 \$6
3266		XOR	\$12 \$11	3332		EXCH	\$11 \$8
3267		EXCH	\$11 \$9	3333		XOR	\$12 \$11
3268		EXCH	\$11 \$8	3334	loadMetAdd_128:	EXCH	\$13 \$12
3269		XOR	\$12 \$11	3335		ADDI	\$13 0
3270	loadMetAdd_123:	EXCH	\$13 \$12	3336		EXCH	\$14 \$13
3271		ADDI	\$13 1	3337		XOR	\$15 \$14
3272		EXCH	\$14 \$13	3338		EXCH	\$14 \$13
3273		XOR	\$15 \$14	3339		ADDI	\$13 0
3274		EXCH	\$14 \$13	3340		EXCH	\$13 \$12
3275		ADDI	\$13 -1	3341		EXCH	\$11 \$8
3276		EXCH	\$13 \$12	3342		EXCH	\$3 \$1
3277		EXCH	\$11 \$8	3343		ADDI	\$1 -1
3278		EXCH	\$3 \$1	3344		EXCH	\$10 \$1
3279		ADDI	\$1 -1	3345		ADDI	\$1 -1
3280		EXCH	\$10 \$1	3346		EXCH	\$9 \$1
3281		ADDI	\$1 -1	3347		ADDI	\$1 -1
3282		EXCH	\$8 \$1	3348		EXCH	\$8 \$1
3283		ADDI	\$1 -1	3349		ADDI	\$1 -1
3284		EXCH	\$7 \$1	3350		EXCH	\$7 \$1
3285		ADDI	\$1 -1	3351		ADDI	\$1 -1
3286		EXCH	\$6 \$1	3352		EXCH	\$6 \$1
3287		ADDI	\$1 -1	3353		ADDI	\$1 -1
3288		EXCH	\$9 \$1	3354		EXCH	\$12 \$1
3289		ADDI	\$1 -1	3355		ADDI	\$1 -1
3290		EXCH	\$12 \$1	3356		ADDI	\$15 -3356
3291		ADDI	\$1 -1	3357	l_rjmp_top_130:	RBRA	l_rjmp_bot_131
3292		ADDI	\$15 -3292	3358	l_rjmp_129:	SWAPBR	\$15
3293	l_rjmp_top_125:	RBRA	l_rjmp_bot_125	3359		NEG	\$15
3294	l_rjmp_124:	SWAPBR	\$15	3360	l_rjmp_bot_131:	BRA	l_rjmp_top_130
3295		NEG	\$15	3361		ADDI	\$15 3356
3296	l_rjmp_bot_126:	BRA	l_rjmp_top_126	3362		ADDI	\$1 1
3297		ADDI	\$15 3292	3363		EXCH	\$12 \$1
3298		ADDI	\$1 1	3364		ADDI	\$1 1
3299		EXCH	\$12 \$1	3365		EXCH	\$6 \$1
3300		ADDI	\$1 1	3366		ADDI	\$1 1
3301		EXCH	\$9 \$1	3367		EXCH	\$7 \$1
3302		ADDI	\$1 1	3368		ADDI	\$1 1
3303		EXCH	\$6 \$1	3369		EXCH	\$8 \$1
3304		ADDI	\$1 1	3370		ADDI	\$1 1
3305		EXCH	\$7 \$1	3371		EXCH	\$9 \$1
3306		ADDI	\$1 1	3372		ADDI	\$1 1
3307		EXCH	\$8 \$1	3373		EXCH	\$10 \$1
3308		ADDI	\$1 1	3374		ADDI	\$1 1
3309		EXCH	\$10 \$1	3375		EXCH	\$3 \$1
3310		ADDI	\$1 1	3376		EXCH	\$11 \$8
3311		EXCH	\$3 \$1	3377		EXCH	\$13 \$12
3312		EXCH	\$11 \$8	3378		ADDI	\$13 0
3313		EXCH	\$13 \$12	3379		EXCH	\$14 \$13
3314		ADDI	\$13 1	3380		XOR	\$15 \$14
3315		EXCH	\$14 \$13	3381		EXCH	\$14 \$13
3316		XOR	\$15 \$14	3382		ADDI	\$13 0
3317		EXCH	\$14 \$13	3383	loadMetAdd_128_i:	EXCH	\$13 \$12
3318		ADDI	\$13 -1	3384		XOR	\$12 \$11
3319	loadMetAdd_123_i:	EXCH	\$13 \$12	3385		EXCH	\$11 \$8
3320		XOR	\$12 \$11	3386		EXCH	\$11 \$7
3321		EXCH	\$11 \$8	3387		XOR	\$12 \$11
3322		EXCH	\$11 \$6	3388	loadMetAdd_132:	EXCH	\$13 \$12
3323		EXCH	\$12 \$7	3389		ADDI	\$13 1
3324	copy_127:	XOR	\$11 \$12	3390		EXCH	\$14 \$13
3325		ADDI	\$12 1	3391		XOR	\$15 \$14

3392		EXCH	\$14 \$13	3458		EXCH	\$11 \$7
3393		ADDI	\$13 -1	3459		XOR	\$12 \$11
3394		EXCH	\$13 \$12	3460	loadMetAdd_137:	EXCH	\$13 \$12
3395		EXCH	\$11 \$7	3461		ADDI	\$13 0
3396		EXCH	\$3 \$1	3462		EXCH	\$14 \$13
3397		ADDI	\$1 -1	3463		XOR	\$15 \$14
3398		EXCH	\$10 \$1	3464		EXCH	\$14 \$13
3399		ADDI	\$1 -1	3465		ADDI	\$13 0
3400		EXCH	\$9 \$1	3466		EXCH	\$13 \$12
3401		ADDI	\$1 -1	3467		EXCH	\$11 \$7
3402		EXCH	\$7 \$1	3468		EXCH	\$3 \$1
3403		ADDI	\$1 -1	3469		ADDI	\$1 -1
3404		EXCH	\$6 \$1	3470		EXCH	\$10 \$1
3405		ADDI	\$1 -1	3471		ADDI	\$1 -1
3406		EXCH	\$8 \$1	3472		EXCH	\$9 \$1
3407		ADDI	\$1 -1	3473		ADDI	\$1 -1
3408		EXCH	\$12 \$1	3474		EXCH	\$8 \$1
3409		ADDI	\$1 -1	3475		ADDI	\$1 -1
3410		ADDI	\$15 -3410	3476		EXCH	\$7 \$1
3411	l_rjmp_top_134:	RBRA	l_rjmp_bot_134	3477		ADDI	\$1 -1
3412	l_jump_133:	SWAPBR	\$15	3478		EXCH	\$6 \$1
3413		NEG	\$15	3479		ADDI	\$1 -1
3414	l_rjmp_bot_135:	BRA	l_rjmp_top_134	3480		EXCH	\$12 \$1
3415		ADDI	\$15 3410	3481		ADDI	\$1 -1
3416		ADDI	\$1 1	3482		ADDI	\$15 -3482
3417		EXCH	\$12 \$1	3483	l_rjmp_top_139:	RBRA	l_rjmp_bot_140
3418		ADDI	\$1 1	3484	l_jump_138:	SWAPBR	\$15
3419		EXCH	\$8 \$1	3485		NEG	\$15
3420		ADDI	\$1 1	3486	l_rjmp_bot_140:	BRA	l_rjmp_top_139
3421		EXCH	\$6 \$1	3487		ADDI	\$15 3482
3422		ADDI	\$1 1	3488		ADDI	\$1 1
3423		EXCH	\$7 \$1	3489		EXCH	\$12 \$1
3424		ADDI	\$1 1	3490		ADDI	\$1 1
3425		EXCH	\$9 \$1	3491		EXCH	\$6 \$1
3426		ADDI	\$1 1	3492		ADDI	\$1 1
3427		EXCH	\$10 \$1	3493		EXCH	\$7 \$1
3428		ADDI	\$1 1	3494		ADDI	\$1 1
3429		EXCH	\$3 \$1	3495		EXCH	\$8 \$1
3430		EXCH	\$11 \$7	3496		ADDI	\$1 1
3431		EXCH	\$13 \$12	3497		EXCH	\$9 \$1
3432		ADDI	\$13 1	3498		ADDI	\$1 1
3433		EXCH	\$14 \$13	3499		EXCH	\$10 \$1
3434		XOR	\$15 \$14	3500		ADDI	\$1 1
3435		EXCH	\$14 \$13	3501		EXCH	\$3 \$1
3436		ADDI	\$13 -1	3502		EXCH	\$11 \$7
3437	loadMetAdd_132_i:	EXCH	\$13 \$12	3503		EXCH	\$13 \$12
3438		XOR	\$12 \$11	3504		ADDI	\$13 0
3439		EXCH	\$11 \$7	3505		EXCH	\$14 \$13
3440		EXCH	\$11 \$6	3506		XOR	\$15 \$14
3441		ADD	\$12 \$3	3507		EXCH	\$14 \$13
3442		ADDI	\$12 2	3508		ADDI	\$13 0
3443		EXCH	\$13 \$12	3509	loadMetAdd_137_i:	EXCH	\$13 \$12
3444		ADDI	\$12 -2	3510		XOR	\$12 \$11
3445		SUB	\$12 \$3	3511		EXCH	\$11 \$7
3446	copy_136:	XOR	\$11 \$13	3512		ADD	\$11 \$3
3447		ADDI	\$13 1	3513		ADDI	\$11 2
3448		EXCH	\$14 \$13	3514		EXCH	\$12 \$11
3449		ADDI	\$14 1	3515		ADDI	\$11 -2
3450		EXCH	\$14 \$13	3516		SUB	\$11 \$3
3451		ADDI	\$13 -1	3517		XOR	\$13 \$12
3452		ADD	\$12 \$3	3518	loadMetAdd_141:	EXCH	\$14 \$13
3453		ADDI	\$12 2	3519		ADDI	\$14 1
3454		EXCH	\$13 \$12	3520		EXCH	\$15 \$14
3455		ADDI	\$12 -2	3521		XOR	\$16 \$15
3456		SUB	\$12 \$3	3522		EXCH	\$15 \$14
3457		EXCH	\$11 \$6	3523		ADDI	\$14 -1

3524		EXCH	\$14 \$13	3590		ADDI	\$1 1
3525		ADD	\$11 \$3	3591		EXCH	\$9 \$1
3526		ADDI	\$11 2	3592		XOR	\$9 \$0
3527		EXCH	\$12 \$11	3593	localBlock_147_i:	XOR	\$8 \$1
3528		ADDI	\$11 -2	3594		ADDI	\$1 1
3529		SUB	\$11 \$3	3595		EXCH	\$8 \$1
3530		EXCH	\$3 \$1	3596		XOR	\$8 \$0
3531		ADDI	\$1 -1	3597	localBlock_148_i:	XOR	\$7 \$1
3532		EXCH	\$10 \$1	3598		ADDI	\$1 1
3533		ADDI	\$1 -1	3599		EXCH	\$7 \$1
3534		EXCH	\$9 \$1	3600		XOR	\$7 \$0
3535		ADDI	\$1 -1	3601	localBlock_149_i:	XOR	\$6 \$1
3536		EXCH	\$8 \$1	3602	l_initTape_3_bot:	BRA	
3537		ADDI	\$1 -1		l_initTape_3_top		
3538		EXCH	\$6 \$1	3603	l_init_4_top:	BRA	l_init_4_bot
3539		ADDI	\$1 -1	3604		ADDI	\$1 1
3540		EXCH	\$7 \$1	3605		EXCH	\$2 \$1
3541		ADDI	\$1 -1	3606		EXCH	\$3 \$1
3542		EXCH	\$13 \$1	3607		ADDI	\$1 -1
3543		ADDI	\$1 -1	3608	l_init_4:	SWAPBR	\$2
3544		ADDI	\$16 -3544	3609		NEG	\$2
3545	l_rjmp_top_143:	RBRA	l_rjmp_bot_144	3610		ADDI	\$1 1
3546	l_jmp_142:	SWAPBR	\$16	3611		EXCH	\$3 \$1
3547		NEG	\$16	3612		EXCH	\$2 \$1
3548	l_rjmp_bot_144:	BRA	l_rjmp_top_143	3613		ADDI	\$1 -1
3549		ADDI	\$16 3544	3614		EXCH	\$3 \$1
3550		ADDI	\$1 1	3615		ADDI	\$1 -1
3551		EXCH	\$13 \$1	3616		BRA	
3552		ADDI	\$1 1			l_initLiterals_1	
3553		EXCH	\$7 \$1	3617		ADDI	\$1 1
3554		ADDI	\$1 1	3618		EXCH	\$3 \$1
3555		EXCH	\$6 \$1	3619		EXCH	\$3 \$1
3556		ADDI	\$1 1	3620		ADDI	\$1 -1
3557		EXCH	\$8 \$1	3621		BRA	l_initRules_2
3558		ADDI	\$1 1	3622		ADDI	\$1 1
3559		EXCH	\$9 \$1	3623		EXCH	\$3 \$1
3560		ADDI	\$1 1	3624		EXCH	\$3 \$1
3561		EXCH	\$10 \$1	3625		ADDI	\$1 -1
3562		ADDI	\$1 1	3626		BRA	l_initTape_3
3563		EXCH	\$3 \$1	3627		ADDI	\$1 1
3564		ADD	\$11 \$3	3628		EXCH	\$3 \$1
3565		ADDI	\$11 2	3629		ADD	\$6 \$3
3566		EXCH	\$12 \$11	3630		ADDI	\$6 11
3567		ADDI	\$11 -2	3631		EXCH	\$7 \$6
3568		SUB	\$11 \$3	3632		ADDI	\$6 -11
3569		EXCH	\$14 \$13	3633		SUB	\$6 \$3
3570		ADDI	\$14 1	3634		XORI	\$8 1
3571		EXCH	\$15 \$14	3635		ADD	\$7 \$8
3572		XOR	\$16 \$15	3636		XORI	\$8 1
3573		EXCH	\$15 \$14	3637		ADD	\$6 \$3
3574		ADDI	\$14 -1	3638		ADDI	\$6 11
3575	loadMetAdd_141_i:	EXCH	\$14 \$13	3639		EXCH	\$7 \$6
3576		XOR	\$13 \$12	3640		ADDI	\$6 -11
3577		ADD	\$11 \$3	3641		SUB	\$6 \$3
3578		ADDI	\$11 2	3642		ADD	\$6 \$3
3579		EXCH	\$12 \$11	3643		ADDI	\$6 12
3580		ADDI	\$11 -2	3644		EXCH	\$7 \$6
3581		SUB	\$11 \$3	3645		ADDI	\$6 -12
3582		ADDI	\$1 1	3646		SUB	\$6 \$3
3583		EXCH	\$11 \$1	3647		XORI	\$8 1
3584		XOR	\$11 \$0	3648		ADD	\$7 \$8
3585	localBlock_145_i:	XOR	\$10 \$1	3649		XORI	\$8 1
3586		ADDI	\$1 1	3650		ADD	\$6 \$3
3587		EXCH	\$10 \$1	3651		ADDI	\$6 12
3588		XOR	\$10 \$0	3652		EXCH	\$7 \$6
3589	localBlock_146_i:	XOR	\$9 \$1	3653		ADDI	\$6 -12

3654		SUB	\$6 \$3	3710		ADD	\$9 \$3
3655		ADD	\$6 \$3	3711		ADDI	\$9 12
3656		ADDI	\$6 13	3712		EXCH	\$10 \$9
3657		EXCH	\$7 \$6	3713		ADDI	\$9 -12
3658		ADDI	\$6 -13	3714		SUB	\$9 \$3
3659		SUB	\$6 \$3	3715		ADD	\$7 \$3
3660		XORI	\$8 6	3716		ADDI	\$7 11
3661		ADD	\$7 \$8	3717		EXCH	\$8 \$7
3662		XORI	\$8 6	3718		ADDI	\$7 -11
3663		ADD	\$6 \$3	3719		SUB	\$7 \$3
3664		ADDI	\$6 13	3720		ADD	\$7 \$3
3665		EXCH	\$7 \$6	3721		ADDI	\$7 2
3666		ADDI	\$6 -13	3722		EXCH	\$8 \$7
3667		SUB	\$6 \$3	3723		ADDI	\$7 -2
3668		EXCH	\$3 \$1	3724		SUB	\$7 \$3
3669		ADDI	\$1 -1	3725		XOR	\$9 \$8
3670		BRA	l_simulate_5	3726	loadMetAdd_158:	EXCH	\$10 \$9
3671		ADDI	\$1 1	3727		ADDI	\$10 3
3672		EXCH	\$3 \$1	3728		EXCH	\$11 \$10
3673	l_init_4_bot:	BRA	l_init_4_top	3729		XOR	\$12 \$11
3674	l_simulate_5_top:	BRA		3730		EXCH	\$11 \$10
	l_simulate_5_bot			3731		ADDI	\$10 -3
3675		ADDI	\$1 1	3732		EXCH	\$10 \$9
3676		EXCH	\$2 \$1	3733		ADD	\$7 \$3
3677		EXCH	\$3 \$1	3734		ADDI	\$7 2
3678		ADDI	\$1 -1	3735		EXCH	\$8 \$7
3679	l_simulate_5:	SWAPBR	\$2	3736		ADDI	\$7 -2
3680		NEG	\$2	3737		SUB	\$7 \$3
3681		ADDI	\$1 1	3738		ADD	\$13 \$3
3682		EXCH	\$3 \$1	3739		ADDI	\$13 14
3683		EXCH	\$2 \$1	3740		EXCH	\$3 \$1
3684		ADDI	\$1 -1	3741		ADDI	\$1 -1
3685		XORI	\$6 1	3742		EXCH	\$13 \$1
3686	entry_150:	BEQ	\$6 \$0	3743		ADDI	\$1 -1
	assert_152			3744		EXCH	\$9 \$1
3687		ADD	\$7 \$3	3745		ADDI	\$1 -1
3688		ADDI	\$7 11	3746		ADDI	\$12 -3745
3689		EXCH	\$8 \$7	3747	l_jump_159:	SWAPBR	\$12
3690		ADDI	\$7 -11	3748		NEG	\$12
3691		SUB	\$7 \$3	3749		ADDI	\$12 3745
3692		ADD	\$9 \$3	3750		ADDI	\$1 1
3693		ADDI	\$9 12	3751		EXCH	\$9 \$1
3694		EXCH	\$10 \$9	3752		ADDI	\$1 1
3695		ADDI	\$9 -12	3753		EXCH	\$13 \$1
3696		SUB	\$9 \$3	3754		ADDI	\$1 1
3697	cmp_top_154:	BNE	\$8 \$10	3755		EXCH	\$3 \$1
	cmp_bot_155			3756		ADDI	\$13 -14
3698		XORI	\$11 1	3757		SUB	\$13 \$3
3699	cmp_bot_155:	BNE	\$8 \$10	3758		ADD	\$7 \$3
	cmp_top_154			3759		ADDI	\$7 2
3700	f_top_156:	BEQ	\$11 \$0	3760		EXCH	\$8 \$7
	f_bot_157			3761		ADDI	\$7 -2
3701		XORI	\$12 1	3762		SUB	\$7 \$3
3702	f_bot_157:	BEQ	\$11 \$0	3763		EXCH	\$10 \$9
	f_top_156			3764		ADDI	\$10 3
3703		XOR	\$6 \$12	3765		EXCH	\$11 \$10
3704	f_bot_157_i:	BEQ	\$11 \$0	3766		XOR	\$12 \$11
	f_top_156_i			3767		EXCH	\$11 \$10
3705		XORI	\$12 1	3768		ADDI	\$10 -3
3706	f_top_156_i:	BEQ	\$11 \$0	3769	loadMetAdd_158_i:	EXCH	\$10 \$9
	f_bot_157_i			3770		XOR	\$9 \$8
3707	cmp_bot_155_i:	BNE	\$8 \$10	3771		ADD	\$7 \$3
	cmp_top_154_i			3772		ADDI	\$7 2
3708		XORI	\$11 1	3773		EXCH	\$8 \$7
3709	cmp_top_154_i:	BNE	\$8 \$10	3774		ADDI	\$7 -2
	cmp_bot_155_i			3775		SUB	\$7 \$3

3776		EXCH	\$3 \$1	3842		ADDI	\$7 -16
3777		ADDI	\$1 -1	3843		SUB	\$7 \$3
3778		BRA	l_inst_6	3844		XORI	\$9 1
3779		ADDI	\$1 1	3845		ADD	\$8 \$9
3780		EXCH	\$3 \$1	3846		XORI	\$9 1
3781		ADD	\$7 \$3	3847		ADD	\$7 \$3
3782		ADDI	\$7 2	3848		ADDI	\$7 16
3783		EXCH	\$8 \$7	3849		EXCH	\$8 \$7
3784		ADDI	\$7 -2	3850		ADDI	\$7 -16
3785		SUB	\$7 \$3	3851		SUB	\$7 \$3
3786		XOR	\$9 \$8	3852		ADD	\$8 \$3
3787	loadMetAdd_160:	EXCH	\$10 \$9	3853		ADDI	\$8 16
3788		ADDI	\$10 3	3854		EXCH	\$9 \$8
3789		EXCH	\$11 \$10	3855		ADDI	\$8 -16
3790		XOR	\$12 \$11	3856		SUB	\$8 \$3
3791		EXCH	\$11 \$10	3857		ADD	\$10 \$3
3792		ADDI	\$10 -3	3858		ADDI	\$10 15
3793		EXCH	\$10 \$9	3859		EXCH	\$11 \$10
3794		ADD	\$7 \$3	3860		ADDI	\$10 -15
3795		ADDI	\$7 2	3861		SUB	\$10 \$3
3796		EXCH	\$8 \$7	3862	cmp_top_168:	BNE	\$9 \$11
3797		ADDI	\$7 -2		cmp_bot_169		
3798		SUB	\$7 \$3	3863		XORI	\$12 1
3799		ADD	\$13 \$3	3864	cmp_bot_169:	BNE	\$9 \$11
3800		ADDI	\$13 14		cmp_top_168		
3801		EXCH	\$3 \$1	3865	f_top_170:	BEQ	\$12 \$0
3802		ADDI	\$1 -1		f_bot_171		
3803		EXCH	\$13 \$1	3866		XORI	\$13 1
3804		ADDI	\$1 -1	3867	f_bot_171:	BEQ	\$12 \$0
3805		EXCH	\$9 \$1		f_top_170		
3806		ADDI	\$1 -1	3868		XOR	\$7 \$13
3807		ADDI	\$12 -3807	3869	f_bot_171_i:	BEQ	\$12 \$0
3808	l_rjmp_top_162:	RBRA	l_rjmp_bot_163		f_top_170_i		
3809	l_jmp_161:	SWAPBR	\$12	3870		XORI	\$13 1
3810		NEG	\$12	3871	f_top_170_i:	BEQ	\$12 \$0
3811	l_rjmp_bot_163:	BRA	l_rjmp_top_162		f_bot_171_i		
3812		ADDI	\$12 3807	3872	cmp_bot_169_i:	BNE	\$9 \$11
3813		ADDI	\$1 1		cmp_top_168_i		
3814		EXCH	\$9 \$1	3873		XORI	\$12 1
3815		ADDI	\$1 1	3874	cmp_top_168_i:	BNE	\$9 \$11
3816		EXCH	\$13 \$1		cmp_bot_169_i		
3817		ADDI	\$1 1	3875		ADD	\$10 \$3
3818		EXCH	\$3 \$1	3876		ADDI	\$10 15
3819		ADDI	\$13 -14	3877		EXCH	\$11 \$10
3820		SUB	\$13 \$3	3878		ADDI	\$10 -15
3821		ADD	\$7 \$3	3879		SUB	\$10 \$3
3822		ADDI	\$7 2	3880		ADD	\$8 \$3
3823		EXCH	\$8 \$7	3881		ADDI	\$8 16
3824		ADDI	\$7 -2	3882		EXCH	\$9 \$8
3825		SUB	\$7 \$3	3883		ADDI	\$8 -16
3826		EXCH	\$10 \$9	3884		SUB	\$8 \$3
3827		ADDI	\$10 3	3885	test_164:	BEQ	\$7 \$0
3828		EXCH	\$11 \$10		test_false_166		
3829		XOR	\$12 \$11	3886		XORI	\$7 1
3830		EXCH	\$11 \$10	3887		ADD	\$8 \$3
3831		ADDI	\$10 -3	3888		ADDI	\$8 16
3832	loadMetAdd_160_i:	EXCH	\$10 \$9	3889		EXCH	\$9 \$8
3833		XOR	\$9 \$8	3890		ADDI	\$8 -16
3834		ADD	\$7 \$3	3891		SUB	\$8 \$3
3835		ADDI	\$7 2	3892		ADD	\$10 \$3
3836		EXCH	\$8 \$7	3893		ADDI	\$10 15
3837		ADDI	\$7 -2	3894		EXCH	\$11 \$10
3838		SUB	\$7 \$3	3895		ADDI	\$10 -15
3839		ADD	\$7 \$3	3896		SUB	\$10 \$3
3840		ADDI	\$7 16	3897		XOR	\$9 \$11
3841		EXCH	\$8 \$7	3898		ADD	\$10 \$3

3899		ADDI	\$10 15	3952	f_bot_179_i:	BEQ	\$11 \$0
3900		EXCH	\$11 \$10		f_top_178_i		
3901		ADDI	\$10 -15	3953		XORI	\$12 1
3902		SUB	\$10 \$3	3954	f_top_178_i:	BEQ	\$11 \$0
3903		ADD	\$8 \$3		f_bot_179_i		
3904		ADDI	\$8 16	3955	cmp_bot_177_i:	BNE	\$8 \$10
3905		EXCH	\$9 \$8		cmp_top_176_i		
3906		ADDI	\$8 -16	3956		XORI	\$11 1
3907		SUB	\$8 \$3	3957	cmp_top_176_i:	BNE	\$8 \$10
3908		XORI	\$7 1		cmp_bot_177_i		
3909	assert_true_165:	BRA	assert_167	3958		ADD	\$9 \$3
3910	test_false_166:	BRA	test_164	3959		ADDI	\$9 13
3911	assert_167:	BNE	\$7 \$0	3960		EXCH	\$10 \$9
	assert_true_165			3961		ADDI	\$9 -13
3912		ADD	\$8 \$3	3962		SUB	\$9 \$3
3913		ADDI	\$8 16	3963		ADD	\$7 \$3
3914		EXCH	\$9 \$8	3964		ADDI	\$7 11
3915		ADDI	\$8 -16	3965		EXCH	\$8 \$7
3916		SUB	\$8 \$3	3966		ADDI	\$7 -11
3917	cmp_top_172:	BNE	\$9 \$0	3967		SUB	\$7 \$3
	cmp_bot_173			3968	test_151:	BNE	\$6 \$0 exit_153
3918		XORI	\$10 1	3969	assert_152:	BRA	entry_150
3919	cmp_bot_173:	BNE	\$9 \$0	3970	exit_153:	BRA	test_151
	cmp_top_172			3971		XORI	\$6 1
3920	f_top_174:	BEQ	\$10 \$0	3972	l_simulate_5_bot:	BRA	
	f_bot_175				l_simulate_5_top		
3921		XORI	\$11 1	3973	l_inst_6_top:	BRA	l_inst_6_bot
3922	f_bot_175:	BEQ	\$10 \$0	3974		ADDI	\$1 1
	f_top_174			3975		EXCH	\$2 \$1
3923		XOR	\$7 \$11	3976		EXCH	\$3 \$1
3924	f_bot_175_i:	BEQ	\$10 \$0	3977		ADDI	\$1 -1
	f_top_174_i			3978	l_inst_6:	SWAPBR	\$2
3925		XORI	\$11 1	3979		NEG	\$2
3926	f_top_174_i:	BEQ	\$10 \$0	3980		ADDI	\$1 1
	f_bot_175_i			3981		EXCH	\$3 \$1
3927	cmp_bot_173_i:	BNE	\$9 \$0	3982		EXCH	\$2 \$1
	cmp_top_172_i			3983		ADDI	\$1 -1
3928		XORI	\$10 1	3984		ADD	\$7 \$3
3929	cmp_top_172_i:	BNE	\$9 \$0	3985		ADDI	\$7 11
	cmp_bot_173_i			3986		EXCH	\$8 \$7
3930		ADD	\$8 \$3	3987		ADDI	\$7 -11
3931		ADDI	\$8 16	3988		SUB	\$7 \$3
3932		EXCH	\$9 \$8	3989		ADD	\$9 \$3
3933		ADDI	\$8 -16	3990		ADDI	\$9 3
3934		SUB	\$8 \$3	3991		ADD	\$10 \$3
3935		ADD	\$7 \$3	3992		ADDI	\$10 16
3936		ADDI	\$7 11	3993		EXCH	\$11 \$10
3937		EXCH	\$8 \$7	3994		ADDI	\$10 -16
3938		ADDI	\$7 -11	3995		SUB	\$10 \$3
3939		SUB	\$7 \$3	3996		EXCH	\$13 \$9
3940		ADD	\$9 \$3	3997		XOR	\$12 \$13
3941		ADDI	\$9 13	3998		EXCH	\$13 \$9
3942		EXCH	\$10 \$9	3999		ADDI	\$12 2
3943		ADDI	\$9 -13	4000		ADD	\$12 \$11
3944		SUB	\$9 \$3	4001		ADD	\$10 \$3
3945	cmp_top_176:	BNE	\$8 \$10	4002		ADDI	\$10 16
	cmp_bot_177			4003		EXCH	\$11 \$10
3946		XORI	\$11 1	4004		ADDI	\$10 -16
3947	cmp_bot_177:	BNE	\$8 \$10	4005		SUB	\$10 \$3
	cmp_top_176			4006		ADDI	\$9 -3
3948	f_top_178:	BEQ	\$11 \$0	4007		SUB	\$9 \$3
	f_bot_179			4008		EXCH	\$14 \$12
3949		XORI	\$12 1	4009		ADD	\$9 \$3
3950	f_bot_179:	BEQ	\$11 \$0	4010		ADDI	\$9 3
	f_top_178			4011		ADD	\$10 \$3
3951		XOR	\$6 \$12	4012		ADDI	\$10 16

4013		EXCH	\$11 \$10	4076		XORI	\$24 1
4014		ADDI	\$10 -16	4077	cmp_bot_187:	BNE	\$17 \$23
4015		SUB	\$10 \$3		cmp_top_186		
4016		SUB	\$12 \$11	4078		ANDX	\$25 \$15 \$24
4017		ADDI	\$12 -2	4079	f_top_188:	BEQ	\$25 \$0
4018		EXCH	\$13 \$9		f_bot_189		
4019		XOR	\$12 \$13	4080		XORI	\$26 1
4020		EXCH	\$13 \$9	4081	f_bot_189:	BEQ	\$25 \$0
4021		ADD	\$10 \$3		f_top_188		
4022		ADDI	\$10 16	4082		XOR	\$6 \$26
4023		EXCH	\$11 \$10	4083	f_bot_189_i:	BEQ	\$25 \$0
4024		ADDI	\$10 -16		f_top_188_i		
4025		SUB	\$10 \$3	4084		XORI	\$26 1
4026		ADDI	\$9 -3	4085	f_top_188_i:	BEQ	\$25 \$0
4027		SUB	\$9 \$3		f_bot_189_i		
4028	cmp_top_184:	BNE	\$8 \$14	4086		ANDX	\$25 \$15 \$24
	cmp_bot_185			4087	cmp_bot_187_i:	BNE	\$17 \$23
4029		XORI	\$15 1		cmp_top_186_i		
4030	cmp_bot_185:	BNE	\$8 \$14	4088		XORI	\$24 1
	cmp_top_184			4089	cmp_top_186_i:	BNE	\$17 \$23
					cmp_bot_187_i		
4031		ADD	\$16 \$3	4090		ADD	\$18 \$3
4032		ADDI	\$16 14	4091		ADDI	\$18 5
4033		EXCH	\$17 \$16	4092		ADD	\$19 \$3
4034		ADDI	\$16 -14	4093		ADDI	\$19 16
4035		SUB	\$16 \$3	4094		EXCH	\$20 \$19
4036		ADD	\$18 \$3	4095		ADDI	\$19 -16
4037		ADDI	\$18 5	4096		SUB	\$19 \$3
4038		ADD	\$19 \$3	4097		EXCH	\$22 \$18
4039		ADDI	\$19 16	4098		XOR	\$21 \$22
4040		EXCH	\$20 \$19	4099		EXCH	\$22 \$18
4041		ADDI	\$19 -16	4100		ADDI	\$21 2
4042		SUB	\$19 \$3	4101		ADD	\$21 \$20
4043		EXCH	\$22 \$18	4102		ADD	\$19 \$3
4044		XOR	\$21 \$22	4103		ADDI	\$19 16
4045		EXCH	\$22 \$18	4104		EXCH	\$20 \$19
4046		ADDI	\$21 2	4105		ADDI	\$19 -16
4047		ADD	\$21 \$20	4106		SUB	\$19 \$3
4048		ADD	\$19 \$3	4107		ADDI	\$18 -5
4049		ADDI	\$19 16	4108		SUB	\$18 \$3
4050		EXCH	\$20 \$19	4109		EXCH	\$23 \$21
4051		ADDI	\$19 -16	4110		ADD	\$18 \$3
4052		SUB	\$19 \$3	4111		ADDI	\$18 5
4053		ADDI	\$18 -5	4112		ADD	\$19 \$3
4054		SUB	\$18 \$3	4113		ADDI	\$19 16
4055		EXCH	\$23 \$21	4114		EXCH	\$20 \$19
4056		ADD	\$18 \$3	4115		ADDI	\$19 -16
4057		ADDI	\$18 5	4116		SUB	\$19 \$3
4058		ADD	\$19 \$3	4117		SUB	\$21 \$20
4059		ADDI	\$19 16	4118		ADDI	\$21 -2
4060		EXCH	\$20 \$19	4119		EXCH	\$22 \$18
4061		ADDI	\$19 -16	4120		XOR	\$21 \$22
4062		SUB	\$19 \$3	4121		EXCH	\$22 \$18
4063		SUB	\$21 \$20	4122		ADD	\$19 \$3
4064		ADDI	\$21 -2	4123		ADDI	\$19 16
4065		EXCH	\$22 \$18	4124		EXCH	\$20 \$19
4066		XOR	\$21 \$22	4125		ADDI	\$19 -16
4067		EXCH	\$22 \$18	4126		SUB	\$19 \$3
4068		ADD	\$19 \$3	4127		ADDI	\$18 -5
4069		ADDI	\$19 16	4128		SUB	\$18 \$3
4070		EXCH	\$20 \$19	4129		ADD	\$16 \$3
4071		ADDI	\$19 -16	4130		ADDI	\$16 14
4072		SUB	\$19 \$3	4131		EXCH	\$17 \$16
4073		ADDI	\$18 -5	4132		ADDI	\$16 -14
4074		SUB	\$18 \$3	4133		SUB	\$16 \$3
4075	cmp_top_186:	BNE	\$17 \$23	4134	cmp_bot_185_i:	BNE	\$8 \$14
	cmp_bot_187						

	cmp_top_184_i			4198		ADDI	\$12 2
4135		XORI	\$15 1	4199		ADD	\$12 \$11
4136	cmp_top_184_i:	BNE	\$8 \$14	4200		ADD	\$10 \$3
	cmp_bot_185_i			4201		ADDI	\$10 16
4137		ADD	\$9 \$3	4202		EXCH	\$11 \$10
4138		ADDI	\$9 3	4203		ADDI	\$10 -16
4139		ADD	\$10 \$3	4204		SUB	\$10 \$3
4140		ADDI	\$10 16	4205		ADDI	\$9 -4
4141		EXCH	\$11 \$10	4206		SUB	\$9 \$3
4142		ADDI	\$10 -16	4207		EXCH	\$14 \$12
4143		SUB	\$10 \$3	4208		ADD	\$9 \$3
4144		EXCH	\$13 \$9	4209		ADDI	\$9 4
4145		XOR	\$12 \$13	4210		ADD	\$10 \$3
4146		EXCH	\$13 \$9	4211		ADDI	\$10 16
4147		ADDI	\$12 2	4212		EXCH	\$11 \$10
4148		ADD	\$12 \$11	4213		ADDI	\$10 -16
4149		ADD	\$10 \$3	4214		SUB	\$10 \$3
4150		ADDI	\$10 16	4215		SUB	\$12 \$11
4151		EXCH	\$11 \$10	4216		ADDI	\$12 -2
4152		ADDI	\$10 -16	4217		EXCH	\$13 \$9
4153		SUB	\$10 \$3	4218		XOR	\$12 \$13
4154		ADDI	\$9 -3	4219		EXCH	\$13 \$9
4155		SUB	\$9 \$3	4220		ADD	\$10 \$3
4156		EXCH	\$14 \$12	4221		ADDI	\$10 16
4157		ADD	\$9 \$3	4222		EXCH	\$11 \$10
4158		ADDI	\$9 3	4223		ADDI	\$10 -16
4159		ADD	\$10 \$3	4224		SUB	\$10 \$3
4160		ADDI	\$10 16	4225		ADDI	\$9 -4
4161		EXCH	\$11 \$10	4226		SUB	\$9 \$3
4162		ADDI	\$10 -16	4227		ADD	\$15 \$3
4163		SUB	\$10 \$3	4228		ADDI	\$15 3
4164		SUB	\$12 \$11	4229		ADD	\$16 \$3
4165		ADDI	\$12 -2	4230		ADDI	\$16 16
4166		EXCH	\$13 \$9	4231		EXCH	\$17 \$16
4167		XOR	\$12 \$13	4232		ADDI	\$16 -16
4168		EXCH	\$13 \$9	4233		SUB	\$16 \$3
4169		ADD	\$10 \$3	4234		EXCH	\$19 \$15
4170		ADDI	\$10 16	4235		XOR	\$18 \$19
4171		EXCH	\$11 \$10	4236		EXCH	\$19 \$15
4172		ADDI	\$10 -16	4237		ADDI	\$18 2
4173		SUB	\$10 \$3	4238		ADD	\$18 \$17
4174		ADDI	\$9 -3	4239		ADD	\$16 \$3
4175		SUB	\$9 \$3	4240		ADDI	\$16 16
4176		ADD	\$7 \$3	4241		EXCH	\$17 \$16
4177		ADDI	\$7 11	4242		ADDI	\$16 -16
4178		EXCH	\$8 \$7	4243		SUB	\$16 \$3
4179		ADDI	\$7 -11	4244		ADDI	\$15 -3
4180		SUB	\$7 \$3	4245		SUB	\$15 \$3
4181	test_180:	BEQ	\$6 \$0	4246		EXCH	\$20 \$18
	test_false_182			4247		ADD	\$15 \$3
4182		XORI	\$6 1	4248		ADDI	\$15 3
4183		ADD	\$7 \$3	4249		ADD	\$16 \$3
4184		ADDI	\$7 11	4250		ADDI	\$16 16
4185		EXCH	\$8 \$7	4251		EXCH	\$17 \$16
4186		ADDI	\$7 -11	4252		ADDI	\$16 -16
4187		SUB	\$7 \$3	4253		SUB	\$16 \$3
4188		ADD	\$9 \$3	4254		SUB	\$18 \$17
4189		ADDI	\$9 4	4255		ADDI	\$18 -2
4190		ADD	\$10 \$3	4256		EXCH	\$19 \$15
4191		ADDI	\$10 16	4257		XOR	\$18 \$19
4192		EXCH	\$11 \$10	4258		EXCH	\$19 \$15
4193		ADDI	\$10 -16	4259		ADD	\$16 \$3
4194		SUB	\$10 \$3	4260		ADDI	\$16 16
4195		EXCH	\$13 \$9	4261		EXCH	\$17 \$16
4196		XOR	\$12 \$13	4262		ADDI	\$16 -16
4197		EXCH	\$13 \$9	4263		SUB	\$16 \$3

4264	ADDI	\$15 -3	4330	ADD	\$9 \$3
4265	SUB	\$15 \$3	4331	ADDI	\$9 4
4266	XOR	\$21 \$14	4332	ADD	\$10 \$3
4267	SUB	\$21 \$20	4333	ADDI	\$10 16
4268	ADD	\$8 \$21	4334	EXCH	\$11 \$10
4269	ADD	\$21 \$20	4335	ADDI	\$10 -16
4270	XOR	\$21 \$14	4336	SUB	\$10 \$3
4271	ADD	\$15 \$3	4337	SUB	\$12 \$11
4272	ADDI	\$15 3	4338	ADDI	\$12 -2
4273	ADD	\$16 \$3	4339	EXCH	\$13 \$9
4274	ADDI	\$16 16	4340	XOR	\$12 \$13
4275	EXCH	\$17 \$16	4341	EXCH	\$13 \$9
4276	ADDI	\$16 -16	4342	ADD	\$10 \$3
4277	SUB	\$16 \$3	4343	ADDI	\$10 16
4278	EXCH	\$19 \$15	4344	EXCH	\$11 \$10
4279	XOR	\$18 \$19	4345	ADDI	\$10 -16
4280	EXCH	\$19 \$15	4346	SUB	\$10 \$3
4281	ADDI	\$18 2	4347	ADDI	\$9 -4
4282	ADD	\$18 \$17	4348	SUB	\$9 \$3
4283	ADD	\$16 \$3	4349	ADD	\$7 \$3
4284	ADDI	\$16 16	4350	ADDI	\$7 11
4285	EXCH	\$17 \$16	4351	EXCH	\$8 \$7
4286	ADDI	\$16 -16	4352	ADDI	\$7 -11
4287	SUB	\$16 \$3	4353	SUB	\$7 \$3
4288	ADDI	\$15 -3	4354	ADD	\$7 \$3
4289	SUB	\$15 \$3	4355	ADDI	\$7 14
4290	EXCH	\$20 \$18	4356	EXCH	\$8 \$7
4291	ADD	\$15 \$3	4357	ADDI	\$7 -14
4292	ADDI	\$15 3	4358	SUB	\$7 \$3
4293	ADD	\$16 \$3	4359	ADD	\$9 \$3
4294	ADDI	\$16 16	4360	ADDI	\$9 6
4295	EXCH	\$17 \$16	4361	ADD	\$10 \$3
4296	ADDI	\$16 -16	4362	ADDI	\$10 16
4297	SUB	\$16 \$3	4363	EXCH	\$11 \$10
4298	SUB	\$18 \$17	4364	ADDI	\$10 -16
4299	ADDI	\$18 -2	4365	SUB	\$10 \$3
4300	EXCH	\$19 \$15	4366	EXCH	\$13 \$9
4301	XOR	\$18 \$19	4367	XOR	\$12 \$13
4302	EXCH	\$19 \$15	4368	EXCH	\$13 \$9
4303	ADD	\$16 \$3	4369	ADDI	\$12 2
4304	ADDI	\$16 16	4370	ADD	\$12 \$11
4305	EXCH	\$17 \$16	4371	ADD	\$10 \$3
4306	ADDI	\$16 -16	4372	ADDI	\$10 16
4307	SUB	\$16 \$3	4373	EXCH	\$11 \$10
4308	ADDI	\$15 -3	4374	ADDI	\$10 -16
4309	SUB	\$15 \$3	4375	SUB	\$10 \$3
4310	ADD	\$9 \$3	4376	ADDI	\$9 -6
4311	ADDI	\$9 4	4377	SUB	\$9 \$3
4312	ADD	\$10 \$3	4378	EXCH	\$14 \$12
4313	ADDI	\$10 16	4379	ADD	\$9 \$3
4314	EXCH	\$11 \$10	4380	ADDI	\$9 6
4315	ADDI	\$10 -16	4381	ADD	\$10 \$3
4316	SUB	\$10 \$3	4382	ADDI	\$10 16
4317	EXCH	\$13 \$9	4383	EXCH	\$11 \$10
4318	XOR	\$12 \$13	4384	ADDI	\$10 -16
4319	EXCH	\$13 \$9	4385	SUB	\$10 \$3
4320	ADDI	\$12 2	4386	SUB	\$12 \$11
4321	ADD	\$12 \$11	4387	ADDI	\$12 -2
4322	ADD	\$10 \$3	4388	EXCH	\$13 \$9
4323	ADDI	\$10 16	4389	XOR	\$12 \$13
4324	EXCH	\$11 \$10	4390	EXCH	\$13 \$9
4325	ADDI	\$10 -16	4391	ADD	\$10 \$3
4326	SUB	\$10 \$3	4392	ADDI	\$10 16
4327	ADDI	\$9 -4	4393	EXCH	\$11 \$10
4328	SUB	\$9 \$3	4394	ADDI	\$10 -16
4329	EXCH	\$14 \$12	4395	SUB	\$10 \$3

4396	ADDI	\$9 -6	4462	ADD	\$15 \$3
4397	SUB	\$9 \$3	4463	ADDI	\$15 5
4398	ADD	\$15 \$3	4464	ADD	\$16 \$3
4399	ADDI	\$15 5	4465	ADDI	\$16 16
4400	ADD	\$16 \$3	4466	EXCH	\$17 \$16
4401	ADDI	\$16 16	4467	ADDI	\$16 -16
4402	EXCH	\$17 \$16	4468	SUB	\$16 \$3
4403	ADDI	\$16 -16	4469	SUB	\$18 \$17
4404	SUB	\$16 \$3	4470	ADDI	\$18 -2
4405	EXCH	\$19 \$15	4471	EXCH	\$19 \$15
4406	XOR	\$18 \$19	4472	XOR	\$18 \$19
4407	EXCH	\$19 \$15	4473	EXCH	\$19 \$15
4408	ADDI	\$18 2	4474	ADD	\$16 \$3
4409	ADD	\$18 \$17	4475	ADDI	\$16 16
4410	ADD	\$16 \$3	4476	EXCH	\$17 \$16
4411	ADDI	\$16 16	4477	ADDI	\$16 -16
4412	EXCH	\$17 \$16	4478	SUB	\$16 \$3
4413	ADDI	\$16 -16	4479	ADDI	\$15 -5
4414	SUB	\$16 \$3	4480	SUB	\$15 \$3
4415	ADDI	\$15 -5	4481	ADD	\$9 \$3
4416	SUB	\$15 \$3	4482	ADDI	\$9 6
4417	EXCH	\$20 \$18	4483	ADD	\$10 \$3
4418	ADD	\$15 \$3	4484	ADDI	\$10 16
4419	ADDI	\$15 5	4485	EXCH	\$11 \$10
4420	ADD	\$16 \$3	4486	ADDI	\$10 -16
4421	ADDI	\$16 16	4487	SUB	\$10 \$3
4422	EXCH	\$17 \$16	4488	EXCH	\$13 \$9
4423	ADDI	\$16 -16	4489	XOR	\$12 \$13
4424	SUB	\$16 \$3	4490	EXCH	\$13 \$9
4425	SUB	\$18 \$17	4491	ADDI	\$12 2
4426	ADDI	\$18 -2	4492	ADD	\$12 \$11
4427	EXCH	\$19 \$15	4493	ADD	\$10 \$3
4428	XOR	\$18 \$19	4494	ADDI	\$10 16
4429	EXCH	\$19 \$15	4495	EXCH	\$11 \$10
4430	ADD	\$16 \$3	4496	ADDI	\$10 -16
4431	ADDI	\$16 16	4497	SUB	\$10 \$3
4432	EXCH	\$17 \$16	4498	ADDI	\$9 -6
4433	ADDI	\$16 -16	4499	SUB	\$9 \$3
4434	SUB	\$16 \$3	4500	EXCH	\$14 \$12
4435	ADDI	\$15 -5	4501	ADD	\$9 \$3
4436	SUB	\$15 \$3	4502	ADDI	\$9 6
4437	XOR	\$21 \$14	4503	ADD	\$10 \$3
4438	SUB	\$21 \$20	4504	ADDI	\$10 16
4439	ADD	\$8 \$21	4505	EXCH	\$11 \$10
4440	ADD	\$21 \$20	4506	ADDI	\$10 -16
4441	XOR	\$21 \$14	4507	SUB	\$10 \$3
4442	ADD	\$15 \$3	4508	SUB	\$12 \$11
4443	ADDI	\$15 5	4509	ADDI	\$12 -2
4444	ADD	\$16 \$3	4510	EXCH	\$13 \$9
4445	ADDI	\$16 16	4511	XOR	\$12 \$13
4446	EXCH	\$17 \$16	4512	EXCH	\$13 \$9
4447	ADDI	\$16 -16	4513	ADD	\$10 \$3
4448	SUB	\$16 \$3	4514	ADDI	\$10 16
4449	EXCH	\$19 \$15	4515	EXCH	\$11 \$10
4450	XOR	\$18 \$19	4516	ADDI	\$10 -16
4451	EXCH	\$19 \$15	4517	SUB	\$10 \$3
4452	ADDI	\$18 2	4518	ADDI	\$9 -6
4453	ADD	\$18 \$17	4519	SUB	\$9 \$3
4454	ADD	\$16 \$3	4520	ADD	\$7 \$3
4455	ADDI	\$16 16	4521	ADDI	\$7 14
4456	EXCH	\$17 \$16	4522	EXCH	\$8 \$7
4457	ADDI	\$16 -16	4523	ADDI	\$7 -14
4458	SUB	\$16 \$3	4524	SUB	\$7 \$3
4459	ADDI	\$15 -5	4525	XORI	\$6 1
4460	SUB	\$15 \$3	4526	BRA	assert_true_181:
4461	EXCH	\$20 \$18	4527	BRA	test_false_182:
					test_180

4528	assert_183:	BNE	\$6 \$0	4591	ADDI	\$21 2
	assert_true_181			4592	ADD	\$21 \$20
4529		ADD	\$7 \$3	4593	ADD	\$19 \$3
4530		ADDI	\$7 11	4594	ADDI	\$19 16
4531		EXCH	\$8 \$7	4595	EXCH	\$20 \$19
4532		ADDI	\$7 -11	4596	ADDI	\$19 -16
4533		SUB	\$7 \$3	4597	SUB	\$19 \$3
4534		ADD	\$9 \$3	4598	ADDI	\$18 -6
4535		ADDI	\$9 4	4599	SUB	\$18 \$3
4536		ADD	\$10 \$3	4600	EXCH	\$23 \$21
4537		ADDI	\$10 16	4601	ADD	\$18 \$3
4538		EXCH	\$11 \$10	4602	ADDI	\$18 6
4539		ADDI	\$10 -16	4603	ADD	\$19 \$3
4540		SUB	\$10 \$3	4604	ADDI	\$19 16
4541		EXCH	\$13 \$9	4605	EXCH	\$20 \$19
4542		XOR	\$12 \$13	4606	ADDI	\$19 -16
4543		EXCH	\$13 \$9	4607	SUB	\$19 \$3
4544		ADDI	\$12 2	4608	SUB	\$21 \$20
4545		ADD	\$12 \$11	4609	ADDI	\$21 -2
4546		ADD	\$10 \$3	4610	EXCH	\$22 \$18
4547		ADDI	\$10 16	4611	XOR	\$21 \$22
4548		EXCH	\$11 \$10	4612	EXCH	\$22 \$18
4549		ADDI	\$10 -16	4613	ADD	\$19 \$3
4550		SUB	\$10 \$3	4614	ADDI	\$19 16
4551		ADDI	\$9 -4	4615	EXCH	\$20 \$19
4552		SUB	\$9 \$3	4616	ADDI	\$19 -16
4553		EXCH	\$14 \$12	4617	SUB	\$19 \$3
4554		ADD	\$9 \$3	4618	ADDI	\$18 -6
4555		ADDI	\$9 4	4619	SUB	\$18 \$3
4556		ADD	\$10 \$3	4620	BNE	\$17 \$23
4557		ADDI	\$10 16	cmp_top_192:		
4558		EXCH	\$11 \$10	cmp_bot_193		
4559		ADDI	\$10 -16	4621	XORI	\$24 1
4560		SUB	\$10 \$3	4622	BNE	\$17 \$23
4561		SUB	\$12 \$11	cmp_bot_193:		
4562		ADDI	\$12 -2	cmp_top_192		
4563		EXCH	\$13 \$9	4623	ANDX	\$25 \$15 \$24
4564		XOR	\$12 \$13	4624	BEQ	\$25 \$0
4565		EXCH	\$13 \$9	f_top_194:		
4566		ADD	\$10 \$3	f_bot_195		
4567		ADDI	\$10 16	4625	XORI	\$26 1
4568		EXCH	\$11 \$10	4626	BEQ	\$25 \$0
4569		ADDI	\$10 -16	f_bot_195:		
4570		SUB	\$10 \$3	f_top_194		
4571		ADDI	\$9 -4	4627	XOR	\$6 \$26
4572		SUB	\$9 \$3	4628	BEQ	\$25 \$0
4573	cmp_top_190:	BNE	\$8 \$14	f_bot_195_i:		
	cmp_bot_191			f_top_194_i		
4574		XORI	\$15 1	4629	XORI	\$26 1
4575	cmp_bot_191:	BNE	\$8 \$14	4630	BEQ	\$25 \$0
	cmp_top_190			f_top_194_i:		
4576		ADD	\$16 \$3	f_bot_195_i		
4577		ADDI	\$16 14	4631	ANDX	\$25 \$15 \$24
4578		EXCH	\$17 \$16	4632	BNE	\$17 \$23
4579		ADDI	\$16 -14	cmp_bot_193_i:		
4580		SUB	\$16 \$3	cmp_top_192_i		
4581		ADD	\$18 \$3	4633	XORI	\$24 1
4582		ADDI	\$18 6	4634	BNE	\$17 \$23
4583		ADD	\$19 \$3	cmp_top_192_i:		
4584		ADDI	\$19 16	cmp_bot_193_i		
4585		EXCH	\$20 \$19	4635	ADD	\$18 \$3
4586		ADDI	\$19 -16	4636	ADDI	\$18 6
4587		SUB	\$19 \$3	4637	ADD	\$19 \$3
4588		EXCH	\$22 \$18	4638	ADDI	\$19 16
4589		XOR	\$21 \$22	4639	EXCH	\$20 \$19
4590		EXCH	\$22 \$18	4640	ADDI	\$19 -16
				4641	SUB	\$19 \$3
				4642	EXCH	\$22 \$18
				4643	XOR	\$21 \$22
				4644	EXCH	\$22 \$18
				4645	ADDI	\$21 2
				4646	ADD	\$21 \$20
				4647	ADD	\$19 \$3
				4648	ADDI	\$19 16

4649		EXCH	\$20 \$19	4713	EXCH	\$13 \$9
4650		ADDI	\$19 -16	4714	ADD	\$10 \$3
4651		SUB	\$19 \$3	4715	ADDI	\$10 16
4652		ADDI	\$18 -6	4716	EXCH	\$11 \$10
4653		SUB	\$18 \$3	4717	ADDI	\$10 -16
4654		EXCH	\$23 \$21	4718	SUB	\$10 \$3
4655		ADD	\$18 \$3	4719	ADDI	\$9 -4
4656		ADDI	\$18 6	4720	SUB	\$9 \$3
4657		ADD	\$19 \$3	4721	ADD	\$7 \$3
4658		ADDI	\$19 16	4722	ADDI	\$7 11
4659		EXCH	\$20 \$19	4723	EXCH	\$8 \$7
4660		ADDI	\$19 -16	4724	ADDI	\$7 -11
4661		SUB	\$19 \$3	4725	SUB	\$7 \$3
4662		SUB	\$21 \$20	4726	ADD	\$7 \$3
4663		ADDI	\$21 -2	4727	ADDI	\$7 11
4664		EXCH	\$22 \$18	4728	EXCH	\$8 \$7
4665		XOR	\$21 \$22	4729	ADDI	\$7 -11
4666		EXCH	\$22 \$18	4730	SUB	\$7 \$3
4667		ADD	\$19 \$3	4731	ADD	\$9 \$3
4668		ADDI	\$19 16	4732	ADDI	\$9 3
4669		EXCH	\$20 \$19	4733	ADD	\$10 \$3
4670		ADDI	\$19 -16	4734	ADDI	\$10 16
4671		SUB	\$19 \$3	4735	EXCH	\$11 \$10
4672		ADDI	\$18 -6	4736	ADDI	\$10 -16
4673		SUB	\$18 \$3	4737	SUB	\$10 \$3
4674		ADD	\$16 \$3	4738	EXCH	\$13 \$9
4675		ADDI	\$16 14	4739	XOR	\$12 \$13
4676		EXCH	\$17 \$16	4740	EXCH	\$13 \$9
4677		ADDI	\$16 -14	4741	ADDI	\$12 2
4678		SUB	\$16 \$3	4742	ADD	\$12 \$11
4679	cmp_bot_191_i:	BNE	\$8 \$14	4743	ADD	\$10 \$3
	cmp_top_190_i			4744	ADDI	\$10 16
4680		XORI	\$15 1	4745	EXCH	\$11 \$10
4681	cmp_top_190_i:	BNE	\$8 \$14	4746	ADDI	\$10 -16
	cmp_bot_191_i			4747	SUB	\$10 \$3
4682		ADD	\$9 \$3	4748	ADDI	\$9 -3
4683		ADDI	\$9 4	4749	SUB	\$9 \$3
4684		ADD	\$10 \$3	4750	EXCH	\$14 \$12
4685		ADDI	\$10 16	4751	ADD	\$9 \$3
4686		EXCH	\$11 \$10	4752	ADDI	\$9 3
4687		ADDI	\$10 -16	4753	ADD	\$10 \$3
4688		SUB	\$10 \$3	4754	ADDI	\$10 16
4689		EXCH	\$13 \$9	4755	EXCH	\$11 \$10
4690		XOR	\$12 \$13	4756	ADDI	\$10 -16
4691		EXCH	\$13 \$9	4757	SUB	\$10 \$3
4692		ADDI	\$12 2	4758	SUB	\$12 \$11
4693		ADD	\$12 \$11	4759	ADDI	\$12 -2
4694		ADD	\$10 \$3	4760	EXCH	\$13 \$9
4695		ADDI	\$10 16	4761	XOR	\$12 \$13
4696		EXCH	\$11 \$10	4762	EXCH	\$13 \$9
4697		ADDI	\$10 -16	4763	ADD	\$10 \$3
4698		SUB	\$10 \$3	4764	ADDI	\$10 16
4699		ADDI	\$9 -4	4765	EXCH	\$11 \$10
4700		SUB	\$9 \$3	4766	ADDI	\$10 -16
4701		EXCH	\$14 \$12	4767	SUB	\$10 \$3
4702		ADD	\$9 \$3	4768	ADDI	\$9 -3
4703		ADDI	\$9 4	4769	SUB	\$9 \$3
4704		ADD	\$10 \$3	4770	BNE	\$8 \$14
4705		ADDI	\$10 16	cmp_top_200:		
4706		EXCH	\$11 \$10	cmp_bot_201		
4707		ADDI	\$10 -16	4771	XORI	\$15 1
4708		SUB	\$10 \$3	4772	BNE	\$8 \$14
4709		SUB	\$12 \$11	cmp_bot_201:		
4710		ADDI	\$12 -2	cmp_top_200		
4711		EXCH	\$13 \$9	4773	ADD	\$16 \$3
4712		XOR	\$12 \$13	4774	ADDI	\$16 5
				4775	ADD	\$17 \$3
				4776	ADDI	\$17 16

4777		EXCH	\$18 \$17	4835		ADDI	\$22 -7
4778		ADDI	\$17 -16	4836		SUB	\$22 \$3
4779		SUB	\$17 \$3	4837		ADD	\$16 \$3
4780		EXCH	\$20 \$16	4838		ADDI	\$16 5
4781		XOR	\$19 \$20	4839		ADD	\$17 \$3
4782		EXCH	\$20 \$16	4840		ADDI	\$17 16
4783		ADDI	\$19 2	4841		EXCH	\$18 \$17
4784		ADD	\$19 \$18	4842		ADDI	\$17 -16
4785		ADD	\$17 \$3	4843		SUB	\$17 \$3
4786		ADDI	\$17 16	4844		EXCH	\$20 \$16
4787		EXCH	\$18 \$17	4845		XOR	\$19 \$20
4788		ADDI	\$17 -16	4846		EXCH	\$20 \$16
4789		SUB	\$17 \$3	4847		ADDI	\$19 2
4790		ADDI	\$16 -5	4848		ADD	\$19 \$18
4791		SUB	\$16 \$3	4849		ADD	\$17 \$3
4792		EXCH	\$21 \$19	4850		ADDI	\$17 16
4793		ADD	\$16 \$3	4851		EXCH	\$18 \$17
4794		ADDI	\$16 5	4852		ADDI	\$17 -16
4795		ADD	\$17 \$3	4853		SUB	\$17 \$3
4796		ADDI	\$17 16	4854		ADDI	\$16 -5
4797		EXCH	\$18 \$17	4855		SUB	\$16 \$3
4798		ADDI	\$17 -16	4856		EXCH	\$21 \$19
4799		SUB	\$17 \$3	4857		ADD	\$16 \$3
4800		SUB	\$19 \$18	4858		ADDI	\$16 5
4801		ADDI	\$19 -2	4859		ADD	\$17 \$3
4802		EXCH	\$20 \$16	4860		ADDI	\$17 16
4803		XOR	\$19 \$20	4861		EXCH	\$18 \$17
4804		EXCH	\$20 \$16	4862		ADDI	\$17 -16
4805		ADD	\$17 \$3	4863		SUB	\$17 \$3
4806		ADDI	\$17 16	4864		SUB	\$19 \$18
4807		EXCH	\$18 \$17	4865		ADDI	\$19 -2
4808		ADDI	\$17 -16	4866		EXCH	\$20 \$16
4809		SUB	\$17 \$3	4867		XOR	\$19 \$20
4810		ADDI	\$16 -5	4868		EXCH	\$20 \$16
4811		SUB	\$16 \$3	4869		ADD	\$17 \$3
4812		ADD	\$22 \$3	4870		ADDI	\$17 16
4813		ADDI	\$22 7	4871		EXCH	\$18 \$17
4814		EXCH	\$23 \$22	4872		ADDI	\$17 -16
4815		ADDI	\$22 -7	4873		SUB	\$17 \$3
4816		SUB	\$22 \$3	4874		ADDI	\$16 -5
4817	cmp_top_202:	BNE	\$21 \$23	4875		SUB	\$16 \$3
4818	cmp_bot_203			4876	cmp_bot_201_i:	BNE	\$8 \$14
4819	cmp_bot_203:	XORI	\$24 1	4877	cmp_top_200_i		
4820	cmp_top_202	BNE	\$21 \$23	4878	cmp_top_200_i:	XORI	\$15 1
4821	f_top_204:			4879	cmp_bot_201_i	BNE	\$8 \$14
4822	f_bot_205	ANDX	\$25 \$15 \$24	4880		ADD	\$9 \$3
4823	f_bot_205:	BEQ	\$25 \$0	4881		ADDI	\$9 3
4824	f_top_204			4882		ADD	\$10 \$3
4825	f_bot_205_i:	XORI	\$26 1	4883		ADDI	\$10 16
4826	f_top_204_i	BEQ	\$25 \$0	4884		EXCH	\$11 -10
4827	f_top_204_i:			4885		ADDI	\$10 -16
4828	f_bot_205_i	XOR	\$6 \$26	4886		SUB	\$10 \$3
4829	cmp_bot_203_i:	BEQ	\$25 \$0	4887		EXCH	\$13 \$9
4830	cmp_top_202_i			4888		XOR	\$12 \$13
4831	cmp_top_202_i:	ANDX	\$25 \$15 \$24	4889		EXCH	\$13 \$9
4832	cmp_bot_203_i	BNE	\$21 \$23	4890		ADDI	\$12 2
4833				4891		ADD	\$12 \$11
4834				4892		ADD	\$10 \$3
		XORI	\$24 1	4893		ADDI	\$10 16
		BNE	\$21 \$23	4894		EXCH	\$11 \$10
				4895		ADDI	\$10 -16
		ADD	\$22 \$3	4896		SUB	\$10 \$3
		ADDI	\$22 7	4897		ADDI	\$9 -3
		EXCH	\$23 \$22	4898		SUB	\$9 \$3
						EXCH	\$14 \$12

4899		ADD	\$9 \$3	4964	EXCH	\$11 \$10
4900		ADDI	\$9 3	4965	ADDI	\$10 -16
4901		ADD	\$10 \$3	4966	SUB	\$10 \$3
4902		ADDI	\$10 16	4967	ADDI	\$9 -4
4903		EXCH	\$11 \$10	4968	SUB	\$9 \$3
4904		ADDI	\$10 -16	4969	ADD	\$15 \$3
4905		SUB	\$10 \$3	4970	ADDI	\$15 3
4906		SUB	\$12 \$11	4971	ADD	\$16 \$3
4907		ADDI	\$12 -2	4972	ADDI	\$16 16
4908		EXCH	\$13 \$9	4973	EXCH	\$17 \$16
4909		XOR	\$12 \$13	4974	ADDI	\$16 -16
4910		EXCH	\$13 \$9	4975	SUB	\$16 \$3
4911		ADD	\$10 \$3	4976	EXCH	\$19 \$15
4912		ADDI	\$10 16	4977	XOR	\$18 \$19
4913		EXCH	\$11 \$10	4978	EXCH	\$19 \$15
4914		ADDI	\$10 -16	4979	ADDI	\$18 2
4915		SUB	\$10 \$3	4980	ADD	\$18 \$17
4916		ADDI	\$9 -3	4981	ADD	\$16 \$3
4917		SUB	\$9 \$3	4982	ADDI	\$16 16
4918		ADD	\$7 \$3	4983	EXCH	\$17 \$16
4919		ADDI	\$7 11	4984	ADDI	\$16 -16
4920		EXCH	\$8 \$7	4985	SUB	\$16 \$3
4921		ADDI	\$7 -11	4986	ADDI	\$15 -3
4922		SUB	\$7 \$3	4987	SUB	\$15 \$3
4923	test_196:	BEQ	\$6 \$0	4988	EXCH	\$20 \$18
	test_false_198			4989	ADD	\$15 \$3
4924		XORI	\$6 1	4990	ADDI	\$15 3
4925		ADD	\$7 \$3	4991	ADD	\$16 \$3
4926		ADDI	\$7 11	4992	ADDI	\$16 16
4927		EXCH	\$8 \$7	4993	EXCH	\$17 \$16
4928		ADDI	\$7 -11	4994	ADDI	\$16 -16
4929		SUB	\$7 \$3	4995	SUB	\$16 \$3
4930		ADD	\$9 \$3	4996	SUB	\$18 \$17
4931		ADDI	\$9 4	4997	ADDI	\$18 -2
4932		ADD	\$10 \$3	4998	EXCH	\$19 \$15
4933		ADDI	\$10 16	4999	XOR	\$18 \$19
4934		EXCH	\$11 \$10	5000	EXCH	\$19 \$15
4935		ADDI	\$10 -16	5001	ADD	\$16 \$3
4936		SUB	\$10 \$3	5002	ADDI	\$16 16
4937		EXCH	\$13 \$9	5003	EXCH	\$17 \$16
4938		XOR	\$12 \$13	5004	ADDI	\$16 -16
4939		EXCH	\$13 \$9	5005	SUB	\$16 \$3
4940		ADDI	\$12 2	5006	ADDI	\$15 -3
4941		ADD	\$12 \$11	5007	SUB	\$15 \$3
4942		ADD	\$10 \$3	5008	XOR	\$21 \$14
4943		ADDI	\$10 16	5009	SUB	\$21 \$20
4944		EXCH	\$11 \$10	5010	ADD	\$8 \$21
4945		ADDI	\$10 -16	5011	ADD	\$21 \$20
4946		SUB	\$10 \$3	5012	XOR	\$21 \$14
4947		ADDI	\$9 -4	5013	ADD	\$15 \$3
4948		SUB	\$9 \$3	5014	ADDI	\$15 3
4949		EXCH	\$14 \$12	5015	ADD	\$16 \$3
4950		ADD	\$9 \$3	5016	ADDI	\$16 16
4951		ADDI	\$9 4	5017	EXCH	\$17 \$16
4952		ADD	\$10 \$3	5018	ADDI	\$16 -16
4953		ADDI	\$10 16	5019	SUB	\$16 \$3
4954		EXCH	\$11 \$10	5020	EXCH	\$19 \$15
4955		ADDI	\$10 -16	5021	XOR	\$18 \$19
4956		SUB	\$10 \$3	5022	EXCH	\$19 \$15
4957		SUB	\$12 \$11	5023	ADDI	\$18 2
4958		ADDI	\$12 -2	5024	ADD	\$18 \$17
4959		EXCH	\$13 \$9	5025	ADD	\$16 \$3
4960		XOR	\$12 \$13	5026	ADDI	\$16 16
4961		EXCH	\$13 \$9	5027	EXCH	\$17 \$16
4962		ADD	\$10 \$3	5028	ADDI	\$16 -16
4963		ADDI	\$10 16	5029	SUB	\$16 \$3

5030	ADDI	\$15 -3	5096	ADD	\$8 \$3
5031	SUB	\$15 \$3	5097	ADDI	\$8 6
5032	EXCH	\$20 \$18	5098	ADD	\$9 \$3
5033	ADD	\$15 \$3	5099	ADDI	\$9 16
5034	ADDI	\$15 3	5100	EXCH	\$10 \$9
5035	ADD	\$16 \$3	5101	ADDI	\$9 -16
5036	ADDI	\$16 16	5102	SUB	\$9 \$3
5037	EXCH	\$17 \$16	5103	EXCH	\$12 \$8
5038	ADDI	\$16 -16	5104	XOR	\$11 \$12
5039	SUB	\$16 \$3	5105	EXCH	\$12 \$8
5040	SUB	\$18 \$17	5106	ADDI	\$11 2
5041	ADDI	\$18 -2	5107	ADD	\$11 \$10
5042	EXCH	\$19 \$15	5108	ADD	\$9 \$3
5043	XOR	\$18 \$19	5109	ADDI	\$9 16
5044	EXCH	\$19 \$15	5110	EXCH	\$10 \$9
5045	ADD	\$16 \$3	5111	ADDI	\$9 -16
5046	ADDI	\$16 16	5112	SUB	\$9 \$3
5047	EXCH	\$17 \$16	5113	ADDI	\$8 -6
5048	ADDI	\$16 -16	5114	SUB	\$8 \$3
5049	SUB	\$16 \$3	5115	EXCH	\$13 \$11
5050	ADDI	\$15 -3	5116	ADD	\$8 \$3
5051	SUB	\$15 \$3	5117	ADDI	\$8 6
5052	ADD	\$9 \$3	5118	ADD	\$9 \$3
5053	ADDI	\$9 4	5119	ADDI	\$9 16
5054	ADD	\$10 \$3	5120	EXCH	\$10 \$9
5055	ADDI	\$10 16	5121	ADDI	\$9 -16
5056	EXCH	\$11 \$10	5122	SUB	\$9 \$3
5057	ADDI	\$10 -16	5123	SUB	\$11 \$10
5058	SUB	\$10 \$3	5124	ADDI	\$11 -2
5059	EXCH	\$13 \$9	5125	EXCH	\$12 \$8
5060	XOR	\$12 \$13	5126	XOR	\$11 \$12
5061	EXCH	\$13 \$9	5127	EXCH	\$12 \$8
5062	ADDI	\$12 2	5128	ADD	\$9 \$3
5063	ADD	\$12 \$11	5129	ADDI	\$9 16
5064	ADD	\$10 \$3	5130	EXCH	\$10 \$9
5065	ADDI	\$10 16	5131	ADDI	\$9 -16
5066	EXCH	\$11 \$10	5132	SUB	\$9 \$3
5067	ADDI	\$10 -16	5133	ADDI	\$8 -6
5068	SUB	\$10 \$3	5134	SUB	\$8 \$3
5069	ADDI	\$9 -4	5135	ADD	\$14 \$3
5070	SUB	\$9 \$3	5136	ADDI	\$14 9
5071	EXCH	\$14 \$12	5137	EXCH	\$15 \$14
5072	ADD	\$9 \$3	5138	ADDI	\$14 -9
5073	ADDI	\$9 4	5139	SUB	\$14 \$3
5074	ADD	\$10 \$3	5140	BNE	\$13 \$15
5075	ADDI	\$10 16			
5076	EXCH	\$11 \$10	5141	XORI	\$16 1
5077	ADDI	\$10 -16	5142	BNE	\$13 \$15
5078	SUB	\$10 \$3			
5079	SUB	\$12 \$11	5143	BEQ	\$16 \$0
5080	ADDI	\$12 -2			
5081	EXCH	\$13 \$9	5144	XORI	\$17 1
5082	XOR	\$12 \$13	5145	BEQ	\$16 \$0
5083	EXCH	\$13 \$9			
5084	ADD	\$10 \$3	5146	XOR	\$7 \$17
5085	ADDI	\$10 16	5147	BEQ	\$16 \$0
5086	EXCH	\$11 \$10			
5087	ADDI	\$10 -16	5148	XORI	\$17 1
5088	SUB	\$10 \$3	5149	BEQ	\$16 \$0
5089	ADDI	\$9 -4			
5090	SUB	\$9 \$3	5150	BNE	\$13 \$15
5091	ADD	\$7 \$3			
5092	ADDI	\$7 11	5151	XORI	\$16 1
5093	EXCH	\$8 \$7	5152	BNE	\$13 \$15
5094	ADDI	\$7 -11			
5095	SUB	\$7 \$3	5153	ADD	\$14 \$3

5154		ADDI	\$14 9	5218	ADDI	\$11 2
5155		EXCH	\$15 \$14	5219	ADD	\$11 \$10
5156		ADDI	\$14 -9	5220	ADD	\$9 \$3
5157		SUB	\$14 \$3	5221	ADDI	\$9 16
5158		ADD	\$8 \$3	5222	EXCH	\$10 \$9
5159		ADDI	\$8 6	5223	ADDI	\$9 -16
5160		ADD	\$9 \$3	5224	SUB	\$9 \$3
5161		ADDI	\$9 16	5225	ADDI	\$8 -6
5162		EXCH	\$10 \$9	5226	SUB	\$8 \$3
5163		ADDI	\$9 -16	5227	EXCH	\$13 \$11
5164		SUB	\$9 \$3	5228	ADD	\$8 \$3
5165		EXCH	\$12 \$8	5229	ADDI	\$8 6
5166		XOR	\$11 \$12	5230	ADD	\$9 \$3
5167		EXCH	\$12 \$8	5231	ADDI	\$9 16
5168		ADDI	\$11 2	5232	EXCH	\$10 \$9
5169		ADD	\$11 \$10	5233	ADDI	\$9 -16
5170		ADD	\$9 \$3	5234	SUB	\$9 \$3
5171		ADDI	\$9 16	5235	SUB	\$11 \$10
5172		EXCH	\$10 \$9	5236	ADDI	\$11 -2
5173		ADDI	\$9 -16	5237	EXCH	\$12 \$8
5174		SUB	\$9 \$3	5238	XOR	\$11 \$12
5175		ADDI	\$8 -6	5239	EXCH	\$12 \$8
5176		SUB	\$8 \$3	5240	ADD	\$9 \$3
5177		EXCH	\$13 \$11	5241	ADDI	\$9 16
5178		ADD	\$8 \$3	5242	EXCH	\$10 \$9
5179		ADDI	\$8 6	5243	ADDI	\$9 -16
5180		ADD	\$9 \$3	5244	SUB	\$9 \$3
5181		ADDI	\$9 16	5245	ADDI	\$8 -6
5182		EXCH	\$10 \$9	5246	SUB	\$8 \$3
5183		ADDI	\$9 -16	5247	ADD	\$14 \$3
5184		SUB	\$9 \$3	5248	ADDI	\$14 9
5185		SUB	\$11 \$10	5249	EXCH	\$15 \$14
5186		ADDI	\$11 -2	5250	ADDI	\$14 -9
5187		EXCH	\$12 \$8	5251	SUB	\$14 \$3
5188		XOR	\$11 \$12	5252	BNE	\$13 \$15
5189		EXCH	\$12 \$8	5253	XORI	\$16 1
5190		ADD	\$9 \$3	5254	BNE	\$13 \$15
5191		ADDI	\$9 16	5255	BEQ	\$16 \$0
5192		EXCH	\$10 \$9	5256	XORI	\$17 1
5193		ADDI	\$9 -16	5257	BEQ	\$16 \$0
5194		SUB	\$9 \$3	5258	XOR	\$7 \$17
5195		ADDI	\$8 -6	5259	BEQ	\$16 \$0
5196		SUB	\$8 \$3	5260	XORI	\$17 1
5197	test_206:	BEQ	\$7 \$0	5261	BEQ	\$16 \$0
5198	test_false_208	XORI	\$7 1	5262	BNE	\$13 \$15
5199		EXCH	\$3 \$1	5263	XORI	\$16 1
5200		ADDI	\$1 -1	5264	BNE	\$13 \$15
5201		BRA	l_moveRight_3261	5265	ADD	\$14 \$3
5202		ADDI	\$1 1	5266	ADDI	\$14 9
5203		EXCH	\$3 \$1	5267	EXCH	\$15 \$14
5204		XORI	\$7 1	5268	ADDI	\$14 -9
5205	assert_true_207:	BRA	assert_209	5269	SUB	\$14 \$3
5206	test_false_208:	BRA	test_206	5270	ADD	\$8 \$3
5207	assert_209:	BNE	\$7 \$0	5271	ADDI	\$8 6
5208	assert_true_207	ADD	\$8 \$3	5272	ADD	\$9 \$3
5209		ADDI	\$8 6	5273	ADDI	\$9 16
5210		ADD	\$9 \$3	5274	EXCH	\$10 \$9
5211		ADDI	\$9 16	5275	ADDI	\$9 -16
5212		EXCH	\$10 \$9			
5213		ADDI	\$9 -16			
5214		SUB	\$9 \$3			
5215		EXCH	\$12 \$8			
5216		XOR	\$11 \$12			
5217		EXCH	\$12 \$8			

5276	SUB	\$9 \$3	5342	ADDI	\$9 16
5277	EXCH	\$12 \$8	5343	EXCH	\$10 \$9
5278	XOR	\$11 \$12	5344	ADDI	\$9 -16
5279	EXCH	\$12 \$8	5345	SUB	\$9 \$3
5280	ADDI	\$11 2	5346	ADDI	\$8 -6
5281	ADD	\$11 \$10	5347	SUB	\$8 \$3
5282	ADD	\$9 \$3	5348	ADD	\$14 \$3
5283	ADDI	\$9 16	5349	ADDI	\$14 8
5284	EXCH	\$10 \$9	5350	EXCH	\$15 \$14
5285	ADDI	\$9 -16	5351	ADDI	\$14 -8
5286	SUB	\$9 \$3	5352	SUB	\$14 \$3
5287	ADDI	\$8 -6	5353	BNE	\$13 \$15
5288	SUB	\$8 \$3			
5289	EXCH	\$13 \$11	5354	XORI	\$16 1
5290	ADD	\$8 \$3	5355	BNE	\$13 \$15
5291	ADDI	\$8 6			
5292	ADD	\$9 \$3	5356	BEQ	\$16 \$0
5293	ADDI	\$9 16			
5294	EXCH	\$10 \$9	5357	XORI	\$17 1
5295	ADDI	\$9 -16	5358	BEQ	\$16 \$0
5296	SUB	\$9 \$3			
5297	SUB	\$11 \$10	5359	XOR	\$7 \$17
5298	ADDI	\$11 -2	5360	BEQ	\$16 \$0
5299	EXCH	\$12 \$8			
5300	XOR	\$11 \$12	5361	XORI	\$17 1
5301	EXCH	\$12 \$8	5362	BEQ	\$16 \$0
5302	ADD	\$9 \$3			
5303	ADDI	\$9 16	5363	BNE	\$13 \$15
5304	EXCH	\$10 \$9			
5305	ADDI	\$9 -16	5364	XORI	\$16 1
5306	SUB	\$9 \$3	5365	BNE	\$13 \$15
5307	ADDI	\$8 -6			
5308	SUB	\$8 \$3	5366	ADD	\$14 \$3
5309	ADD	\$8 \$3	5367	ADDI	\$14 8
5310	ADDI	\$8 6	5368	EXCH	\$15 \$14
5311	ADD	\$9 \$3	5369	ADDI	\$14 -8
5312	ADDI	\$9 16	5370	SUB	\$14 \$3
5313	EXCH	\$10 \$9	5371	ADD	\$8 \$3
5314	ADDI	\$9 -16	5372	ADDI	\$8 6
5315	SUB	\$9 \$3	5373	ADD	\$9 \$3
5316	EXCH	\$12 \$8	5374	ADDI	\$9 16
5317	XOR	\$11 \$12	5375	EXCH	\$10 \$9
5318	EXCH	\$12 \$8	5376	ADDI	\$9 -16
5319	ADDI	\$11 2	5377	SUB	\$9 \$3
5320	ADD	\$11 \$10	5378	EXCH	\$12 \$8
5321	ADD	\$9 \$3	5379	XOR	\$11 \$12
5322	ADDI	\$9 16	5380	EXCH	\$12 \$8
5323	EXCH	\$10 \$9	5381	ADDI	\$11 2
5324	ADDI	\$9 -16	5382	ADD	\$11 \$10
5325	SUB	\$9 \$3	5383	ADD	\$9 \$3
5326	ADDI	\$8 -6	5384	ADDI	\$9 16
5327	SUB	\$8 \$3	5385	EXCH	\$10 \$9
5328	EXCH	\$13 \$11	5386	ADDI	\$9 -16
5329	ADD	\$8 \$3	5387	SUB	\$9 \$3
5330	ADDI	\$8 6	5388	ADDI	\$8 -6
5331	ADD	\$9 \$3	5389	SUB	\$8 \$3
5332	ADDI	\$9 16	5390	EXCH	\$13 \$11
5333	EXCH	\$10 \$9	5391	ADD	\$8 \$3
5334	ADDI	\$9 -16	5392	ADDI	\$8 6
5335	SUB	\$9 \$3	5393	ADD	\$9 \$3
5336	SUB	\$11 \$10	5394	ADDI	\$9 16
5337	ADDI	\$11 -2	5395	EXCH	\$10 \$9
5338	EXCH	\$12 \$8	5396	ADDI	\$9 -16
5339	XOR	\$11 \$12	5397	SUB	\$9 \$3
5340	EXCH	\$12 \$8	5398	SUB	\$11 \$10
5341	ADD	\$9 \$3	5399	ADDI	\$11 -2

5400		EXCH	\$12 \$8	5464		SUB	\$14 \$3
5401		XOR	\$11 \$12	5465	cmp_top_226:	BNE	\$13 \$15
5402		EXCH	\$12 \$8		cmp_bot_227		
5403		ADD	\$9 \$3	5466		XORI	\$16 1
5404		ADDI	\$9 16	5467	cmp_bot_227:	BNE	\$13 \$15
5405		EXCH	\$10 \$9		cmp_top_226		
5406		ADDI	\$9 -16	5468	f_top_228:	BEQ	\$16 \$0
5407		SUB	\$9 \$3		f_bot_229		
5408		ADDI	\$8 -6	5469		XORI	\$17 1
5409		SUB	\$8 \$3	5470	f_bot_229:	BEQ	\$16 \$0
5410	test_218:	BEQ	\$7 \$0		f_top_228		
	test_false_220			5471		XOR	\$7 \$17
5411		XORI	\$7 1	5472	f_bot_229_i:	BEQ	\$16 \$0
5412		EXCH	\$3 \$1		f_top_228_i		
5413		ADDI	\$1 -1	5473		XORI	\$17 1
5414		RBRA	l_moveRight_3	5474	f_top_228_i:	BEQ	\$16 \$0
5415		ADDI	\$1 1		f_bot_229_i		
5416		EXCH	\$3 \$1	5475	cmp_bot_227_i:	BNE	\$13 \$15
5417		XORI	\$7 1		cmp_top_226_i		
5418	assert_true_219:	BRA	assert_221	5476		XORI	\$16 1
5419	test_false_220:	BRA	test_218	5477	cmp_top_226_i:	BNE	\$13 \$15
5420	assert_221:	BNE	\$7 \$0		cmp_bot_227_i		
	assert_true_219			5478		ADD	\$14 \$3
5421		ADD	\$8 \$3	5479		ADDI	\$14 8
5422		ADDI	\$8 6	5480		EXCH	\$15 \$14
5423		ADD	\$9 \$3	5481		ADDI	\$14 -8
5424		ADDI	\$9 16	5482		SUB	\$14 \$3
5425		EXCH	\$10 \$9	5483		ADD	\$8 \$3
5426		ADDI	\$9 -16	5484		ADDI	\$8 6
5427		SUB	\$9 \$3	5485		ADD	\$9 \$3
5428		EXCH	\$12 \$8	5486		ADDI	\$9 16
5429		XOR	\$11 \$12	5487		EXCH	\$10 \$9
5430		EXCH	\$12 \$8	5488		ADDI	\$9 -16
5431		ADDI	\$11 2	5489		SUB	\$9 \$3
5432		ADD	\$11 \$10	5490		EXCH	\$12 \$8
5433		ADD	\$9 \$3	5491		XOR	\$11 \$12
5434		ADDI	\$9 16	5492		EXCH	\$12 \$8
5435		EXCH	\$10 \$9	5493		ADDI	\$11 2
5436		ADDI	\$9 -16	5494		ADD	\$11 \$10
5437		SUB	\$9 \$3	5495		ADD	\$9 \$3
5438		ADDI	\$8 -6	5496		ADDI	\$9 16
5439		SUB	\$8 \$3	5497		EXCH	\$10 \$9
5440		EXCH	\$13 \$11	5498		ADDI	\$9 -16
5441		ADD	\$8 \$3	5499		SUB	\$9 \$3
5442		ADDI	\$8 6	5500		ADDI	\$8 -6
5443		ADD	\$9 \$3	5501		SUB	\$8 \$3
5444		ADDI	\$9 16	5502		EXCH	\$13 \$11
5445		EXCH	\$10 \$9	5503		ADD	\$8 \$3
5446		ADDI	\$9 -16	5504		ADDI	\$8 6
5447		SUB	\$9 \$3	5505		ADD	\$9 \$3
5448		SUB	\$11 \$10	5506		ADDI	\$9 16
5449		ADDI	\$11 -2	5507		EXCH	\$10 \$9
5450		EXCH	\$12 \$8	5508		ADDI	\$9 -16
5451		XOR	\$11 \$12	5509		SUB	\$9 \$3
5452		EXCH	\$12 \$8	5510		SUB	\$11 \$10
5453		ADD	\$9 \$3	5511		ADDI	\$11 -2
5454		ADDI	\$9 16	5512		EXCH	\$12 \$8
5455		EXCH	\$10 \$9	5513		XOR	\$11 \$12
5456		ADDI	\$9 -16	5514		EXCH	\$12 \$8
5457		SUB	\$9 \$3	5515		ADD	\$9 \$3
5458		ADDI	\$8 -6	5516		ADDI	\$9 16
5459		SUB	\$8 \$3	5517		EXCH	\$10 \$9
5460		ADD	\$14 \$3	5518		ADDI	\$9 -16
5461		ADDI	\$14 8	5519		SUB	\$9 \$3
5462		EXCH	\$15 \$14	5520		ADDI	\$8 -6
5463		ADDI	\$14 -8	5521		SUB	\$8 \$3

5522		XORI	\$6 1	5585		ADD	\$17 \$3
5523	assert_true_197:	BRA	assert_199	5586		ADDI	\$17 16
5524	test_false_198:	BRA	test_196	5587		EXCH	\$18 \$17
5525	assert_199:	BNE	\$6 \$0	5588		ADDI	\$17 -16
	assert_true_197			5589		SUB	\$17 \$3
5526		ADD	\$7 \$3	5590		ADDI	\$16 -5
5527		ADDI	\$7 11	5591		SUB	\$16 \$3
5528		EXCH	\$8 \$7	5592		EXCH	\$21 \$19
5529		ADDI	\$7 -11	5593		ADD	\$16 \$3
5530		SUB	\$7 \$3	5594		ADDI	\$16 5
5531		ADD	\$9 \$3	5595		ADD	\$17 \$3
5532		ADDI	\$9 4	5596		ADDI	\$17 16
5533		ADD	\$10 \$3	5597		EXCH	\$18 \$17
5534		ADDI	\$10 16	5598		ADDI	\$17 -16
5535		EXCH	\$11 \$10	5599		SUB	\$17 \$3
5536		ADDI	\$10 -16	5600		SUB	\$19 \$18
5537		SUB	\$10 \$3	5601		ADDI	\$19 -2
5538		EXCH	\$13 \$9	5602		EXCH	\$20 \$16
5539		XOR	\$12 \$13	5603		XOR	\$19 \$20
5540		EXCH	\$13 \$9	5604		EXCH	\$20 \$16
5541		ADDI	\$12 2	5605		ADD	\$17 \$3
5542		ADD	\$12 \$11	5606		ADDI	\$17 16
5543		ADD	\$10 \$3	5607		EXCH	\$18 \$17
5544		ADDI	\$10 16	5608		ADDI	\$17 -16
5545		EXCH	\$11 \$10	5609		SUB	\$17 \$3
5546		ADDI	\$10 -16	5610		ADDI	\$16 -5
5547		SUB	\$10 \$3	5611		SUB	\$16 \$3
5548		ADDI	\$9 -4	5612		ADD	\$22 \$3
5549		SUB	\$9 \$3	5613		ADDI	\$22 7
5550		EXCH	\$14 \$12	5614		EXCH	\$23 \$22
5551		ADD	\$9 \$3	5615		ADDI	\$22 -7
5552		ADDI	\$9 4	5616		SUB	\$22 \$3
5553		ADD	\$10 \$3	5617	cmp_top_232:	BNE	\$21 \$23
5554		ADDI	\$10 16		cmp_bot_233		
5555		EXCH	\$11 \$10	5618		XORI	\$24 1
5556		ADDI	\$10 -16	5619	cmp_bot_233:	BNE	\$21 \$23
5557		SUB	\$10 \$3		cmp_top_232		
5558		SUB	\$12 \$11	5620		ANDX	\$25 \$15 \$24
5559		ADDI	\$12 -2	5621	f_top_234:	BEQ	\$25 \$0
5560		EXCH	\$13 \$9		f_bot_235		
5561		XOR	\$12 \$13	5622		XORI	\$26 1
5562		EXCH	\$13 \$9	5623	f_bot_235:	BEQ	\$25 \$0
5563		ADD	\$10 \$3		f_top_234		
5564		ADDI	\$10 16	5624		XOR	\$6 \$26
5565		EXCH	\$11 \$10	5625	f_bot_235_i:	BEQ	\$25 \$0
5566		ADDI	\$10 -16		f_top_234_i		
5567		SUB	\$10 \$3	5626		XORI	\$26 1
5568		ADDI	\$9 -4	5627	f_top_234_i:	BEQ	\$25 \$0
5569		SUB	\$9 \$3		f_bot_235_i		
5570	cmp_top_230:	BNE	\$8 \$14	5628		ANDX	\$25 \$15 \$24
	cmp_bot_231			5629	cmp_bot_233_i:	BNE	\$21 \$23
5571		XORI	\$15 1		cmp_top_232_i		
5572	cmp_bot_231:	BNE	\$8 \$14	5630		XORI	\$24 1
	cmp_top_230			5631	cmp_top_232_i:	BNE	\$21 \$23
					cmp_bot_233_i		
5573		ADD	\$16 \$3			ADD	\$22 \$3
5574		ADDI	\$16 5	5632		ADDI	\$22 7
5575		ADD	\$17 \$3	5633		EXCH	\$23 \$22
5576		ADDI	\$17 16	5634		ADDI	\$22 -7
5577		EXCH	\$18 \$17	5635		SUB	\$22 \$3
5578		ADDI	\$17 -16	5636		ADD	\$16 \$3
5579		SUB	\$17 \$3	5637		ADDI	\$16 5
5580		EXCH	\$20 \$16	5638		ADD	\$17 \$3
5581		XOR	\$19 \$20	5639		ADDI	\$17 16
5582		EXCH	\$20 \$16	5640		EXCH	\$18 \$17
5583		ADDI	\$19 2	5641		ADDI	\$17 -16
5584		ADD	\$19 \$18	5642			

5643		SUB	\$17 \$3	5707		ADDI	\$12 -2
5644		EXCH	\$20 \$16	5708		EXCH	\$13 \$9
5645		XOR	\$19 \$20	5709		XOR	\$12 \$13
5646		EXCH	\$20 \$16	5710		EXCH	\$13 \$9
5647		ADDI	\$19 2	5711		ADD	\$10 \$3
5648		ADD	\$19 \$18	5712		ADDI	\$10 16
5649		ADD	\$17 \$3	5713		EXCH	\$11 \$10
5650		ADDI	\$17 16	5714		ADDI	\$10 -16
5651		EXCH	\$18 \$17	5715		SUB	\$10 \$3
5652		ADDI	\$17 -16	5716		ADDI	\$9 -4
5653		SUB	\$17 \$3	5717		SUB	\$9 \$3
5654		ADDI	\$16 -5	5718		ADD	\$7 \$3
5655		SUB	\$16 \$3	5719		ADDI	\$7 11
5656		EXCH	\$21 \$19	5720		EXCH	\$8 \$7
5657		ADD	\$16 \$3	5721		ADDI	\$7 -11
5658		ADDI	\$16 5	5722		SUB	\$7 \$3
5659		ADD	\$17 \$3	5723	l_inst_6_bot:	BRA	l_inst_6_top
5660		ADDI	\$17 16	5724	l_moveRight_7_top:	BRA	
5661		EXCH	\$18 \$17		l_moveRight_7_bot		
5662		ADDI	\$17 -16	5725		ADDI	\$1 1
5663		SUB	\$17 \$3	5726		EXCH	\$2 \$1
5664		SUB	\$19 \$18	5727		EXCH	\$3 \$1
5665		ADDI	\$19 -2	5728		ADDI	\$1 -1
5666		EXCH	\$20 \$16	5729	l_moveRight_7:	SWAPBR	\$2
5667		XOR	\$19 \$20	5730		NEG	\$2
5668		EXCH	\$20 \$16	5731		ADDI	\$1 1
5669		ADD	\$17 \$3	5732		EXCH	\$3 \$1
5670		ADDI	\$17 16	5733		EXCH	\$2 \$1
5671		EXCH	\$18 \$17	5734		ADDI	\$1 -1
5672		ADDI	\$17 -16	5735	localBlock_302:	XOR	\$6 \$1
5673		SUB	\$17 \$3	5736		XOR	\$7 \$0
5674		ADDI	\$16 -5	5737		EXCH	\$7 \$1
5675		SUB	\$16 \$3	5738		ADDI	\$1 -1
5676	cmp_bot_231_i:	BNE	\$8 \$14	5739	localBlock_301:	XOR	\$7 \$1
	cmp_top_230_i			5740		XOR	\$8 \$0
5677		XORI	\$15 1	5741		EXCH	\$8 \$1
5678	cmp_top_230_i:	BNE	\$8 \$14	5742		ADDI	\$1 -1
	cmp_bot_231_i			5743		ADD	\$8 \$3
5679		ADD	\$9 \$3	5744		ADDI	\$8 2
5680		ADDI	\$9 4	5745		EXCH	\$9 \$8
5681		ADD	\$10 \$3	5746		ADDI	\$8 -2
5682		ADDI	\$10 16	5747		SUB	\$8 \$3
5683		EXCH	\$11 \$10	5748		XOR	\$10 \$9
5684		ADDI	\$10 -16	5749	loadMetAdd_236:	EXCH	\$11 \$10
5685		SUB	\$10 \$3	5750		ADDI	\$11 3
5686		EXCH	\$13 \$9	5751		EXCH	\$12 \$11
5687		XOR	\$12 \$13	5752		XOR	\$13 \$12
5688		EXCH	\$13 \$9	5753		EXCH	\$12 \$11
5689		ADDI	\$12 2	5754		ADDI	\$11 -3
5690		ADD	\$12 \$11	5755		EXCH	\$11 \$10
5691		ADD	\$10 \$3	5756		ADD	\$8 \$3
5692		ADDI	\$10 16	5757		ADDI	\$8 2
5693		EXCH	\$11 \$10	5758		EXCH	\$9 \$8
5694		ADDI	\$10 -16	5759		ADDI	\$8 -2
5695		SUB	\$10 \$3	5760		SUB	\$8 \$3
5696		ADDI	\$9 -4	5761		ADD	\$14 \$3
5697		SUB	\$9 \$3	5762		ADDI	\$14 14
5698		EXCH	\$14 \$12	5763		EXCH	\$3 \$1
5699		ADD	\$9 \$3	5764		ADDI	\$1 -1
5700		ADDI	\$9 4	5765		EXCH	\$7 \$1
5701		ADD	\$10 \$3	5766		ADDI	\$1 -1
5702		ADDI	\$10 16	5767		EXCH	\$6 \$1
5703		EXCH	\$11 \$10	5768		ADDI	\$1 -1
5704		ADDI	\$10 -16	5769		EXCH	\$14 \$1
5705		SUB	\$10 \$3	5770		ADDI	\$1 -1
5706		SUB	\$12 \$11	5771		EXCH	\$10 \$1

5772		ADDI	\$1 -1	5838		ADDI	\$13 5834
5773		ADDI	\$13 -5773	5839		ADDI	\$1 1
5774	l_rjmp_top_238:	RBRA	l_rjmp_bot_237	5840		EXCH	\$10 \$1
5775	l_rjmp_237:	SWAPBR	\$13	5841		ADDI	\$1 1
5776		NEG	\$13	5842		EXCH	\$6 \$1
5777	l_rjmp_bot_239:	BRA	l_rjmp_top_238	5843		ADDI	\$1 1
5778		ADDI	\$13 5773	5844		EXCH	\$7 \$1
5779		ADDI	\$1 1	5845		ADDI	\$1 1
5780		EXCH	\$10 \$1	5846		EXCH	\$3 \$1
5781		ADDI	\$1 1	5847		ADD	\$8 \$3
5782		EXCH	\$14 \$1	5848		ADDI	\$8 2
5783		ADDI	\$1 1	5849		EXCH	\$9 \$8
5784		EXCH	\$6 \$1	5850		ADDI	\$8 -2
5785		ADDI	\$1 1	5851		SUB	\$8 \$3
5786		EXCH	\$7 \$1	5852		EXCH	\$11 \$10
5787		ADDI	\$1 1	5853		ADDI	\$11 1
5788		EXCH	\$3 \$1	5854		EXCH	\$12 \$11
5789		ADDI	\$14 -14	5855		XOR	\$13 \$12
5790		SUB	\$14 \$3	5856		EXCH	\$12 \$11
5791		ADD	\$8 \$3	5857		ADDI	\$11 -1
5792		ADDI	\$8 2	5858	loadMetAdd_240_i:	EXCH	\$11 \$10
5793		EXCH	\$9 \$8	5859		XOR	\$10 \$9
5794		ADDI	\$8 -2	5860		ADD	\$8 \$3
5795		SUB	\$8 \$3	5861		ADDI	\$8 2
5796		EXCH	\$11 \$10	5862		EXCH	\$9 \$8
5797		ADDI	\$11 3	5863		ADDI	\$8 -2
5798		EXCH	\$12 \$11	5864		SUB	\$8 \$3
5799		XOR	\$13 \$12	5865		EXCH	\$9 \$6
5800		EXCH	\$12 \$11	5866	cmp_top_246:	BNE	\$9 \$0
5801		ADDI	\$11 -3		cmp_bot_247		
5802	loadMetAdd_236_i:	EXCH	\$11 \$10	5867		XORI	\$10 1
5803		XOR	\$10 \$9	5868	cmp_bot_247:	BNE	\$9 \$0
5804		ADD	\$8 \$3		cmp_top_246		
5805		ADDI	\$8 2	5869		ADD	\$11 \$3
5806		EXCH	\$9 \$8	5870		ADDI	\$11 14
5807		ADDI	\$8 -2	5871		EXCH	\$12 \$11
5808		SUB	\$8 \$3	5872		ADDI	\$11 -14
5809		ADD	\$8 \$3	5873		SUB	\$11 \$3
5810		ADDI	\$8 2	5874		ADD	\$13 \$3
5811		EXCH	\$9 \$8	5875		ADDI	\$13 10
5812		ADDI	\$8 -2	5876		EXCH	\$14 \$13
5813		SUB	\$8 \$3	5877		ADDI	\$13 -10
5814		XOR	\$10 \$9	5878		SUB	\$13 \$3
5815	loadMetAdd_240:	EXCH	\$11 \$10	5879	cmp_top_248:	BNE	\$12 \$14
5816		ADDI	\$11 1		cmp_bot_249		
5817		EXCH	\$12 \$11	5880		XORI	\$15 1
5818		XOR	\$13 \$12	5881	cmp_bot_249:	BNE	\$12 \$14
5819		EXCH	\$12 \$11		cmp_top_248		
5820		ADDI	\$11 -1	5882		ANDX	\$16 \$10 \$15
5821		EXCH	\$11 \$10	5883	f_top_250:	BEQ	\$16 \$0
5822		ADD	\$8 \$3		f_bot_251		
5823		ADDI	\$8 2	5884		XORI	\$17 1
5824		EXCH	\$9 \$8	5885	f_bot_251:	BEQ	\$16 \$0
5825		ADDI	\$8 -2		f_top_250		
5826		SUB	\$8 \$3	5886		XOR	\$8 \$17
5827		EXCH	\$3 \$1	5887	f_bot_251_i:	BEQ	\$16 \$0
5828		ADDI	\$1 -1		f_top_250_i		
5829		EXCH	\$7 \$1	5888		XORI	\$17 1
5830		ADDI	\$1 -1	5889	f_top_250_i:	BEQ	\$16 \$0
5831		EXCH	\$6 \$1		f_bot_251_i		
5832		ADDI	\$1 -1	5890		ANDX	\$16 \$10 \$15
5833		EXCH	\$10 \$1	5891	cmp_bot_249_i:	BNE	\$12 \$14
5834		ADDI	\$1 -1		cmp_top_248_i		
5835		ADDI	\$13 -5834	5892		XORI	\$15 1
5836	l_rjmp_241:	SWAPBR	\$13	5893	cmp_top_248_i:	BNE	\$12 \$14
5837		NEG	\$13		cmp_bot_249_i		

5894		ADD	\$13 \$3	5957		XORI	\$10 1
5895		ADDI	\$13 10	5958		EXCH	\$10 \$9
5896		EXCH	\$14 \$13	5959	obj_con_252_bot:	ADDI	\$9 -1
5897		ADDI	\$13 -10	5960		EXCH	\$9 \$6
5898		SUB	\$13 \$3	5961		EXCH	\$9 \$7
5899		ADD	\$11 \$3	5962		EXCH	\$10 \$6
5900		ADDI	\$11 14	5963	copy_253:	XOR	\$9 \$10
5901		EXCH	\$12 \$11	5964		ADDI	\$10 1
5902		ADDI	\$11 -14	5965		EXCH	\$11 \$10
5903		SUB	\$11 \$3	5966		ADDI	\$11 1
5904	cmp_bot_247_i:	BNE	\$9 \$0	5967		EXCH	\$11 \$10
	cmp_top_246_i			5968		ADDI	\$10 -1
5905		XORI	\$10 1	5969		EXCH	\$10 \$6
5906	cmp_top_246_i:	BNE	\$9 \$0	5970		EXCH	\$9 \$7
	cmp_bot_247_i			5971		EXCH	\$9 \$6
5907		EXCH	\$9 \$6	5972		XOR	\$10 \$9
5908	test_242:	BEQ	\$8 \$0	5973	loadMetAdd_254:	EXCH	\$11 \$10
	test_false_244			5974		ADDI	\$11 2
5909		XORI	\$8 1	5975		EXCH	\$12 \$11
5910		ADD	\$9 \$3	5976		XOR	\$13 \$12
5911		ADDI	\$9 14	5977		EXCH	\$12 \$11
5912		EXCH	\$10 \$9	5978		ADDI	\$11 -2
5913		ADDI	\$9 -14	5979		EXCH	\$11 \$10
5914		SUB	\$9 \$3	5980		EXCH	\$9 \$6
5915		ADD	\$11 \$3	5981		EXCH	\$3 \$1
5916		ADDI	\$11 10	5982		ADDI	\$1 -1
5917		EXCH	\$12 \$11	5983		EXCH	\$6 \$1
5918		ADDI	\$11 -10	5984		ADDI	\$1 -1
5919		SUB	\$11 \$3	5985		EXCH	\$7 \$1
5920		XOR	\$10 \$12	5986		ADDI	\$1 -1
5921		ADD	\$11 \$3	5987		EXCH	\$10 \$1
5922		ADDI	\$11 10	5988		ADDI	\$1 -1
5923		EXCH	\$12 \$11	5989		ADDI	\$13 -5989
5924		ADDI	\$11 -10	5990	l_rjmp_top_256:	RBRA	l_rjmp_bot_257
5925		SUB	\$11 \$3	5991	l_jmp_255:	SWAPBR	\$13
5926		ADD	\$9 \$3	5992		NEG	\$13
5927		ADDI	\$9 14	5993	l_rjmp_bot_257:	BRA	l_rjmp_top_256
5928		EXCH	\$10 \$9	5994		ADDI	\$13 5989
5929		ADDI	\$9 -14	5995		ADDI	\$1 1
5930		SUB	\$9 \$3	5996		EXCH	\$10 \$1
5931		EXCH	\$3 \$1	5997		ADDI	\$1 1
5932		ADDI	\$1 -1	5998		EXCH	\$7 \$1
5933		EXCH	\$7 \$1	5999		ADDI	\$1 1
5934		ADDI	\$1 -1	6000		EXCH	\$6 \$1
5935		EXCH	\$6 \$1	6001		ADDI	\$1 1
5936		ADDI	\$1 -1	6002		EXCH	\$3 \$1
5937	obj_con_252:	ADDI	\$10 8	6003		EXCH	\$9 \$6
5938		EXCH	\$10 \$1	6004		EXCH	\$11 \$10
5939		ADDI	\$1 -1	6005		ADDI	\$11 2
5940		EXCH	\$9 \$1	6006		EXCH	\$12 \$11
5941		BRA	\$1 -1	6007		XOR	\$13 \$12
5942		BRA	l_malloc	6008		EXCH	\$12 \$11
5943		ADDI	\$1 1	6009		ADDI	\$11 -2
5944		EXCH	\$9 \$1	6010	loadMetAdd_254_i:	EXCH	\$11 \$10
5945		ADDI	\$1 1	6011		XOR	\$10 \$9
5946		EXCH	\$10 \$1	6012		EXCH	\$9 \$6
5947	obj_con_252_i:	ADDI	\$10 -8	6013		EXCH	\$9 \$6
5948		ADDI	\$1 1	6014		XOR	\$10 \$9
5949		EXCH	\$6 \$1	6015	loadMetAdd_258:	EXCH	\$11 \$10
5950		ADDI	\$1 1	6016		ADDI	\$11 0
5951		EXCH	\$7 \$1	6017		EXCH	\$12 \$11
5952		ADDI	\$1 1	6018		XOR	\$13 \$12
5953		EXCH	\$3 \$1	6019		EXCH	\$12 \$11
5954		XORI	\$10 10	6020		ADDI	\$11 0
5955		EXCH	\$10 \$9	6021		EXCH	\$11 \$10
5956		ADDI	\$9 1	6022		EXCH	\$9 \$6

6023		ADD	\$14 \$3	6089	EXCH	\$11 \$10
6024		ADDI	\$14 2	6090	EXCH	\$9 \$6
6025		EXCH	\$3 \$1	6091	EXCH	\$3 \$1
6026		ADDI	\$1 -1	6092	ADDI	\$1 -1
6027		EXCH	\$7 \$1	6093	EXCH	\$6 \$1
6028		ADDI	\$1 -1	6094	ADDI	\$1 -1
6029		EXCH	\$6 \$1	6095	EXCH	\$7 \$1
6030		ADDI	\$1 -1	6096	ADDI	\$1 -1
6031		EXCH	\$14 \$1	6097	EXCH	\$10 \$1
6032		ADDI	\$1 -1	6098	ADDI	\$1 -1
6033		EXCH	\$10 \$1	6099	ADDI	\$13 -6098
6034		ADDI	\$1 -1	6100	SWAPBR	\$13
6035		ADDI	\$13 -6035	6101	NEG	\$13
6036	l_rjmp_top_260:	RBRA	l_rjmp_bot_261	6102	ADDI	\$13 6098
6037	l_jmp_259:	SWAPBR	\$13	6103	ADDI	\$1 1
6038		NEG	\$13	6104	EXCH	\$10 \$1
6039	l_rjmp_bot_261:	BRA	l_rjmp_top_260	6105	ADDI	\$1 1
6040		ADDI	\$13 6035	6106	EXCH	\$7 \$1
6041		ADDI	\$1 1	6107	ADDI	\$1 1
6042		EXCH	\$10 \$1	6108	EXCH	\$6 \$1
6043		ADDI	\$1 1	6109	ADDI	\$1 1
6044		EXCH	\$14 \$1	6110	EXCH	\$3 \$1
6045		ADDI	\$1 1	6111	EXCH	\$9 \$6
6046		EXCH	\$6 \$1	6112	EXCH	\$11 \$10
6047		ADDI	\$1 1	6113	ADDI	\$11 0
6048		EXCH	\$7 \$1	6114	EXCH	\$12 \$11
6049		ADDI	\$1 1	6115	XOR	\$13 \$12
6050		EXCH	\$3 \$1	6116	EXCH	\$12 \$11
6051		ADDI	\$14 -2	6117	ADDI	\$11 0
6052		SUB	\$14 \$3	6118	EXCH	\$11 \$10
6053		EXCH	\$9 \$6	6119	XOR	\$10 \$9
6054		EXCH	\$11 \$10	6120	EXCH	\$9 \$6
6055		ADDI	\$11 0	6121	ADD	\$9 \$3
6056		EXCH	\$12 \$11	6122	ADDI	\$9 2
6057		XOR	\$13 \$12	6123	EXCH	\$10 \$9
6058		EXCH	\$12 \$11	6124	ADDI	\$9 -2
6059		ADDI	\$11 0	6125	SUB	\$9 \$3
6060	loadMetAdd_258_i:	EXCH	\$11 \$10	6126	EXCH	\$11 \$7
6061		XOR	\$10 \$9	6127	XOR	\$10 \$11
6062		EXCH	\$9 \$6	6128	ADDI	\$11 1
6063		EXCH	\$9 \$6	6129	EXCH	\$12 \$11
6064		ADD	\$10 \$3	6130	ADDI	\$12 -1
6065		ADDI	\$10 2	6131	EXCH	\$12 \$11
6066		EXCH	\$11 \$10	6132	ADDI	\$11 -1
6067		ADDI	\$10 -2	6133	EXCH	\$11 \$7
6068		SUB	\$10 \$3	6134	ADD	\$9 \$3
6069	swap_262:	XOR	\$9 \$11	6135	ADDI	\$9 2
6070		XOR	\$11 \$9	6136	EXCH	\$10 \$9
6071		XOR	\$9 \$11	6137	ADDI	\$9 -2
6072		ADD	\$10 \$3	6138	SUB	\$9 \$3
6073		ADDI	\$10 2	6139	ADD	\$10 \$3
6074		EXCH	\$11 \$10	6140	ADDI	\$10 2
6075		ADDI	\$10 -2	6141	EXCH	\$11 \$10
6076		SUB	\$10 \$3	6142	ADDI	\$10 -2
6077		EXCH	\$9 \$6	6143	SUB	\$10 \$3
6078		XORI	\$8 1	6144	BNE	\$11 \$0
6079	assert_true_243:	BRA	assert_245	6145	XORI	\$12 1
6080	test_false_244:	BRA	test_242	6146	BNE	\$11 \$0
6081		EXCH	\$9 \$6			
6082		XOR	\$10 \$9			
6083	loadMetAdd_263:	EXCH	\$11 \$10			
6084		ADDI	\$11 0			
6085		EXCH	\$12 \$11			
6086		XOR	\$13 \$12			
6087		EXCH	\$12 \$11			
6088		ADDI	\$11 0			

6153		ADDI	\$15 10	6208		EXCH	\$6 \$1
6154		EXCH	\$16 \$15	6209		ADDI	\$1 -1
6155		ADDI	\$15 -10	6210		EXCH	\$15 \$1
6156		SUB	\$15 \$3	6211		ADDI	\$1 -1
6157	cmp_top_272:	BNE	\$14 \$16	6212		EXCH	\$11 \$1
	cmp_bot_273			6213		ADDI	\$1 -1
6158		XORI	\$17 1	6214		ADDI	\$14 -6213
6159	cmp_bot_273:	BNE	\$14 \$16	6215	l_jmp_277:	SWAPBR	\$14
	cmp_top_272			6216		NEG	\$14
6160		ANDX	\$18 \$12 \$17	6217		ADDI	\$14 6213
6161	f_top_274:	BEQ	\$18 \$0	6218		ADDI	\$1 1
	f_bot_275			6219		EXCH	\$11 \$1
6162		XORI	\$19 1	6220		ADDI	\$1 1
6163	f_bot_275:	BEQ	\$18 \$0	6221		EXCH	\$15 \$1
	f_top_274			6222		ADDI	\$1 1
6164		XOR	\$9 \$19	6223		EXCH	\$6 \$1
6165	f_bot_275_i:	BEQ	\$18 \$0	6224		ADDI	\$1 1
	f_top_274_i			6225		EXCH	\$7 \$1
6166		XORI	\$19 1	6226		ADDI	\$1 1
6167	f_top_274_i:	BEQ	\$18 \$0	6227		EXCH	\$3 \$1
	f_bot_275_i			6228		ADDI	\$15 -2
6168		ANDX	\$18 \$12 \$17	6229		SUB	\$15 \$3
6169	cmp_bot_273_i:	BNE	\$14 \$16	6230		EXCH	\$10 \$7
	cmp_top_272_i			6231		EXCH	\$12 \$11
6170		XORI	\$17 1	6232		ADDI	\$12 2
6171	cmp_top_272_i:	BNE	\$14 \$16	6233		EXCH	\$13 \$12
	cmp_bot_273_i			6234		XOR	\$14 \$13
6172		ADD	\$15 \$3	6235		EXCH	\$13 \$12
6173		ADDI	\$15 10	6236		ADDI	\$12 -2
6174		EXCH	\$16 \$15	6237	loadMetAdd_276_i:	EXCH	\$12 \$11
6175		ADDI	\$15 -10	6238		XOR	\$11 \$10
6176		SUB	\$15 \$3	6239		EXCH	\$10 \$7
6177		ADD	\$13 \$3	6240		ADD	\$10 \$3
6178		ADDI	\$13 14	6241		ADDI	\$10 2
6179		EXCH	\$14 \$13	6242		EXCH	\$11 \$10
6180		ADDI	\$13 -14	6243		ADDI	\$10 -2
6181		SUB	\$13 \$3	6244		SUB	\$10 \$3
6182	cmp_bot_271_i:	BNE	\$11 \$0	6245		EXCH	\$12 \$7
	cmp_top_270_i			6246	uncopy_278:	XOR	\$11 \$12
6183		XORI	\$12 1	6247		ADDI	\$12 1
6184	cmp_top_270_i:	BNE	\$11 \$0	6248		EXCH	\$13 \$12
	cmp_bot_271_i			6249		ADDI	\$13 -1
6185		ADD	\$10 \$3	6250		EXCH	\$13 \$12
6186		ADDI	\$10 2	6251		ADDI	\$12 -1
6187		EXCH	\$11 \$10	6252		EXCH	\$12 \$7
6188		ADDI	\$10 -2	6253		ADD	\$10 \$3
6189		SUB	\$10 \$3	6254		ADDI	\$10 2
6190	test_266:	BEQ	\$9 \$0	6255		EXCH	\$11 \$10
	test_false_268			6256		ADDI	\$10 -2
6191		XORI	\$9 1	6257		SUB	\$10 \$3
6192		EXCH	\$10 \$7	6258		EXCH	\$10 \$7
6193		XOR	\$11 \$10	6259	obj_des_279_top:	EXCH	\$11 \$10
6194	loadMetAdd_276:	EXCH	\$12 \$11	6260		XORI	\$11 10
6195		ADDI	\$12 2	6261		ADDI	\$10 1
6196		EXCH	\$13 \$12	6262		EXCH	\$11 \$10
6197		XOR	\$14 \$13	6263		XORI	\$11 1
6198		EXCH	\$13 \$12	6264		ADDI	\$10 -1
6199		ADDI	\$12 -2	6265		EXCH	\$3 \$1
6200		EXCH	\$12 \$11	6266		ADDI	\$1 -1
6201		EXCH	\$10 \$7	6267		EXCH	\$7 \$1
6202		ADD	\$15 \$3	6268		ADDI	\$1 -1
6203		ADDI	\$15 2	6269		EXCH	\$6 \$1
6204		EXCH	\$3 \$1	6270		ADDI	\$1 -1
6205		ADDI	\$1 -1	6271	obj_des_279:	ADDI	\$11 8
6206		EXCH	\$7 \$1	6272		EXCH	\$11 \$1
6207		ADDI	\$1 -1	6273		ADDI	\$1 -1

6274		EXCH	\$10 \$1	6331	loadMetAdd_284:	EXCH	\$11 \$10
6275		ADDI	\$1 -1	6332		ADDI	\$11 0
6276		RBRA	l_malloc	6333		EXCH	\$12 \$11
6277		ADDI	\$1 1	6334		XOR	\$13 \$12
6278		EXCH	\$10 \$1	6335		EXCH	\$12 \$11
6279		ADDI	\$1 1	6336		ADDI	\$11 0
6280		EXCH	\$11 \$1	6337		EXCH	\$11 \$10
6281	obj_des_279_i:	ADDI	\$11 -8	6338		EXCH	\$9 \$6
6282		ADDI	\$1 1	6339		EXCH	\$3 \$1
6283		EXCH	\$6 \$1	6340		ADDI	\$1 -1
6284		ADDI	\$1 1	6341		EXCH	\$6 \$1
6285		EXCH	\$7 \$1	6342		ADDI	\$1 -1
6286		ADDI	\$1 1	6343		EXCH	\$7 \$1
6287		EXCH	\$3 \$1	6344		ADDI	\$1 -1
6288		EXCH	\$10 \$7	6345		EXCH	\$10 \$1
6289		ADD	\$10 \$3	6346		ADDI	\$1 -1
6290		ADDI	\$10 14	6347		ADDI	\$13 -6347
6291		EXCH	\$11 \$10	6348	l_rjmp_top_286:	RBRA	l_rjmp_bot_287
6292		ADDI	\$10 -14	6349	l_jmp_285:	SWAPBR	\$13
6293		SUB	\$10 \$3	6350		NEG	\$13
6294		ADD	\$12 \$3	6351	l_rjmp_bot_287:	BRA	l_rjmp_top_286
6295		ADDI	\$12 10	6352		ADDI	\$13 6347
6296		EXCH	\$13 \$12	6353		ADDI	\$1 1
6297		ADDI	\$12 -10	6354		EXCH	\$10 \$1
6298		SUB	\$12 \$3	6355		ADDI	\$1 1
6299		XOR	\$11 \$13	6356		EXCH	\$7 \$1
6300		ADD	\$12 \$3	6357		ADDI	\$1 1
6301		ADDI	\$12 10	6358		EXCH	\$6 \$1
6302		EXCH	\$13 \$12	6359		ADDI	\$1 1
6303		ADDI	\$12 -10	6360		EXCH	\$3 \$1
6304		SUB	\$12 \$3	6361		EXCH	\$9 \$6
6305		ADD	\$10 \$3	6362		EXCH	\$11 \$10
6306		ADDI	\$10 14	6363		ADDI	\$11 0
6307		EXCH	\$11 \$10	6364		EXCH	\$12 \$11
6308		ADDI	\$10 -14	6365		XOR	\$13 \$12
6309		SUB	\$10 \$3	6366		EXCH	\$12 \$11
6310		XORI	\$9 1	6367		ADDI	\$11 0
6311	assert_true_267:	BRA	assert_269	6368	loadMetAdd_284_i:	EXCH	\$11 \$10
6312	test_false_268:	BRA	test_266	6369		XOR	\$10 \$9
6313	assert_269:	BNE	\$9 \$0	6370		EXCH	\$9 \$6
	assert_true_267			6371		ADD	\$9 \$3
6314		EXCH	\$10 \$7	6372		ADDI	\$9 2
6315	cmp_top_280:	BNE	\$10 \$0	6373		EXCH	\$10 \$9
	cmp_bot_281			6374		ADDI	\$9 -2
6316		XORI	\$11 1	6375		SUB	\$9 \$3
6317	cmp_bot_281:	BNE	\$10 \$0	6376		EXCH	\$11 \$6
	cmp_top_280			6377	swap_288:	XOR	\$10 \$11
6318	f_top_282:	BEQ	\$11 \$0	6378		XOR	\$11 \$10
	f_bot_283			6379		XOR	\$10 \$11
6319		XORI	\$12 1	6380		EXCH	\$11 \$6
6320	f_bot_283:	BEQ	\$11 \$0	6381		ADD	\$9 \$3
	f_top_282			6382		ADDI	\$9 2
6321		XOR	\$9 \$12	6383		EXCH	\$10 \$9
6322	f_bot_283_i:	BEQ	\$11 \$0	6384		ADDI	\$9 -2
	f_top_282_i			6385		SUB	\$9 \$3
6323		XORI	\$12 1	6386		ADD	\$9 \$3
6324	f_top_282_i:	BEQ	\$11 \$0	6387		ADDI	\$9 2
	f_bot_283_i			6388		EXCH	\$10 \$9
6325	cmp_bot_281_i:	BNE	\$10 \$0	6389		ADDI	\$9 -2
	cmp_top_280_i			6390		SUB	\$9 \$3
6326		XORI	\$11 1	6391		XOR	\$11 \$10
6327	cmp_top_280_i:	BNE	\$10 \$0	6392	loadMetAdd_289:	EXCH	\$12 \$11
	cmp_bot_281_i			6393		ADDI	\$12 1
6328		EXCH	\$10 \$7	6394		EXCH	\$13 \$12
6329		EXCH	\$9 \$6	6395		XOR	\$14 \$13
6330		XOR	\$10 \$9	6396		EXCH	\$13 \$12

6397		ADDI	\$12 -1	6463		ADDI	\$1 -1
6398		EXCH	\$12 \$11	6464		EXCH	\$7 \$1
6399		ADD	\$9 \$3	6465		ADDI	\$1 -1
6400		ADDI	\$9 2	6466		EXCH	\$6 \$1
6401		EXCH	\$10 \$9	6467		ADDI	\$1 -1
6402		ADDI	\$9 -2	6468		EXCH	\$15 \$1
6403		SUB	\$9 \$3	6469		ADDI	\$1 -1
6404		EXCH	\$3 \$1	6470		EXCH	\$11 \$1
6405		ADDI	\$1 -1	6471		ADDI	\$1 -1
6406		EXCH	\$7 \$1	6472		ADDI	\$14 -6471
6407		ADDI	\$1 -1	6473	l_jump_292:	SWAPBR	\$14
6408		EXCH	\$6 \$1	6474		NEG	\$14
6409		ADDI	\$1 -1	6475		ADDI	\$14 6471
6410		EXCH	\$11 \$1	6476		ADDI	\$1 1
6411		ADDI	\$1 -1	6477		EXCH	\$11 \$1
6412		ADDI	\$14 -6411	6478		ADDI	\$1 1
6413	l_jump_290:	SWAPBR	\$14	6479		EXCH	\$15 \$1
6414		NEG	\$14	6480		ADDI	\$1 1
6415		ADDI	\$14 6411	6481		EXCH	\$6 \$1
6416		ADDI	\$1 1	6482		ADDI	\$1 1
6417		EXCH	\$11 \$1	6483		EXCH	\$7 \$1
6418		ADDI	\$1 1	6484		ADDI	\$1 1
6419		EXCH	\$6 \$1	6485		EXCH	\$3 \$1
6420		ADDI	\$1 1	6486		ADDI	\$15 -14
6421		EXCH	\$7 \$1	6487		SUB	\$15 \$3
6422		ADDI	\$1 1	6488		ADD	\$9 \$3
6423		EXCH	\$3 \$1	6489		ADDI	\$9 2
6424		ADD	\$9 \$3	6490		EXCH	\$10 \$9
6425		ADDI	\$9 2	6491		ADDI	\$9 -2
6426		EXCH	\$10 \$9	6492		SUB	\$9 \$3
6427		ADDI	\$9 -2	6493		EXCH	\$12 \$11
6428		SUB	\$9 \$3	6494		ADDI	\$12 3
6429		EXCH	\$12 \$11	6495		EXCH	\$13 \$12
6430		ADDI	\$12 1	6496		XOR	\$14 \$13
6431		EXCH	\$13 \$12	6497		EXCH	\$13 \$12
6432		XOR	\$14 \$13	6498		ADDI	\$12 -3
6433		EXCH	\$13 \$12	6499	loadMetAdd_291_i:	EXCH	\$12 \$11
6434		ADDI	\$12 -1	6500		XOR	\$11 \$10
6435	loadMetAdd_289_i:	EXCH	\$12 \$11	6501		ADD	\$9 \$3
6436		XOR	\$11 \$10	6502		ADDI	\$9 2
6437		ADD	\$9 \$3	6503		EXCH	\$10 \$9
6438		ADDI	\$9 2	6504		ADDI	\$9 -2
6439		EXCH	\$10 \$9	6505		SUB	\$9 \$3
6440		ADDI	\$9 -2	6506	assert_245:	BNE	\$8 \$0
6441		SUB	\$9 \$3		assert_true_243		
6442		ADD	\$9 \$3	6507		EXCH	\$9 \$6
6443		ADDI	\$9 2	6508	cmp_top_293:	BNE	\$9 \$0
6444		EXCH	\$10 \$9		cmp_bot_294		
6445		ADDI	\$9 -2	6509		XORI	\$10 1
6446		SUB	\$9 \$3	6510	cmp_bot_294:	BNE	\$9 \$0
6447		XOR	\$11 \$10		cmp_top_293		
6448	loadMetAdd_291:	EXCH	\$12 \$11	6511	f_top_295:	BEQ	\$10 \$0
6449		ADDI	\$12 3		f_bot_296		
6450		EXCH	\$13 \$12	6512		XORI	\$11 1
6451		XOR	\$14 \$13	6513	f_bot_296:	BEQ	\$10 \$0
6452		EXCH	\$13 \$12		f_top_295		
6453		ADDI	\$12 -3	6514		XOR	\$8 \$11
6454		EXCH	\$12 \$11	6515	f_bot_296_i:	BEQ	\$10 \$0
6455		ADD	\$9 \$3		f_top_295_i		
6456		ADDI	\$9 2	6516		XORI	\$11 1
6457		EXCH	\$10 \$9	6517	f_top_295_i:	BEQ	\$10 \$0
6458		ADDI	\$9 -2		f_bot_296_i		
6459		SUB	\$9 \$3	6518	cmp_bot_294_i:	BNE	\$9 \$0
6460		ADD	\$15 \$3		cmp_top_293_i		
6461		ADDI	\$15 14	6519		XORI	\$10 1
6462		EXCH	\$3 \$1	6520	cmp_top_293_i:	BNE	\$9 \$0

6521	cmp_bot_294_i	EXCH	\$9 \$6	6586	XOR	\$7 \$0
6522		ADD	\$8 \$3	6587	localBlock_302_i:	XOR \$6 \$1
6523		ADDI	\$8 2	6588	l_moveRight_7_bot:	BRA
6524		EXCH	\$9 \$8		l_moveRight_7_top	
6525		ADDI	\$8 -2	6589	l_main_0_top:	BRA l_main_0_bot
6526		SUB	\$8 \$3	6590		ADDI \$1 1
6527		XOR	\$10 \$9	6591		EXCH \$2 \$1
6528	loadMetAdd_297:	EXCH	\$11 \$10	6592		EXCH \$3 \$1
6529		ADDI	\$11 1	6593		ADDI \$1 -1
6530		EXCH	\$12 \$11	6594	l_main_0:	SWAPBR \$2
6531		XOR	\$13 \$12	6595		NEG \$2
6532		EXCH	\$12 \$11	6596		ADDI \$1 1
6533		ADDI	\$11 -1	6597		EXCH \$3 \$1
6534		EXCH	\$11 \$10	6598		EXCH \$2 \$1
6535		ADD	\$8 \$3	6599		ADDI \$1 -1
6536		ADDI	\$8 2	6600		EXCH \$3 \$1
6537		EXCH	\$9 \$8	6601		ADDI \$1 -1
6538		ADDI	\$8 -2	6602	obj_con_303:	ADDI \$8 32
6539		SUB	\$8 \$3	6603		EXCH \$8 \$1
6540		EXCH	\$3 \$1	6604		ADDI \$1 -1
6541		ADDI	\$1 -1	6605		EXCH \$7 \$1
6542		EXCH	\$7 \$1	6606		ADDI \$1 -1
6543		ADDI	\$1 -1	6607		BRA l_malloc
6544		EXCH	\$6 \$1	6608		ADDI \$1 1
6545		ADDI	\$1 -1	6609		EXCH \$7 \$1
6546		EXCH	\$10 \$1	6610		ADDI \$1 1
6547		ADDI	\$1 -1	6611		EXCH \$8 \$1
6548		ADDI	\$13 -6548	6612	obj_con_303_i:	ADDI \$8 -32
6549	l_rjmp_top_299:	RBRA	l_rjmp_bot_300	6613		ADDI \$1 1
6550	l_jump_298:	SWAPBR	\$13	6614		EXCH \$3 \$1
6551		NEG	\$13	6615		ADD \$6 \$3
6552	l_rjmp_bot_300:	BRA	l_rjmp_top_299	6616		ADDI \$6 2
6553		ADDI	\$13 6548	6617		XORI \$8 3
6554		ADDI	\$1 1	6618		EXCH \$8 \$7
6555		EXCH	\$10 \$1	6619		ADDI \$7 1
6556		ADDI	\$1 1	6620		XORI \$8 1
6557		EXCH	\$6 \$1	6621		EXCH \$8 \$7
6558		ADDI	\$1 1	6622	obj_con_303_bot:	ADDI \$7 -1
6559		EXCH	\$7 \$1	6623		EXCH \$7 \$6
6560		ADDI	\$1 1	6624		ADDI \$6 -2
6561		EXCH	\$3 \$1	6625		SUB \$6 \$3
6562		ADD	\$8 \$3	6626		ADD \$6 \$3
6563		ADDI	\$8 2	6627		ADDI \$6 2
6564		EXCH	\$9 \$8	6628		EXCH \$7 \$6
6565		ADDI	\$8 -2	6629		ADDI \$6 -2
6566		SUB	\$8 \$3	6630		SUB \$6 \$3
6567		EXCH	\$11 \$10	6631		XOR \$8 \$7
6568		ADDI	\$11 1	6632	loadMetAdd_304:	EXCH \$9 \$8
6569		EXCH	\$12 \$11	6633		ADDI \$9 3
6570		XOR	\$13 \$12	6634		EXCH \$10 \$9
6571		EXCH	\$12 \$11	6635		XOR \$11 \$10
6572		ADDI	\$11 -1	6636		EXCH \$10 \$9
6573	loadMetAdd_297_i:	EXCH	\$11 \$10	6637		ADDI \$9 -3
6574		XOR	\$10 \$9	6638		EXCH \$9 \$8
6575		ADD	\$8 \$3	6639		ADD \$6 \$3
6576		ADDI	\$8 2	6640		ADDI \$6 2
6577		EXCH	\$9 \$8	6641		EXCH \$7 \$6
6578		ADDI	\$8 -2	6642		ADDI \$6 -2
6579		SUB	\$8 \$3	6643		SUB \$6 \$3
6580		ADDI	\$1 1	6644		EXCH \$3 \$1
6581		EXCH	\$8 \$1	6645		ADDI \$1 -1
6582		XOR	\$8 \$0	6646		EXCH \$8 \$1
6583	localBlock_301_i:	XOR	\$7 \$1	6647		ADDI \$1 -1
6584		ADDI	\$1 1	6648		ADDI \$11 -6647
6585		EXCH	\$7 \$1	6649	l_jump_305:	SWAPBR \$11
				6650		NEG \$11

6651		ADDI	\$11 6647	6684	ADDI	\$4 1
6652		ADDI	\$1 1	6685	ADDI	\$4 -10
6653		EXCH	\$8 \$1	6686	XOR	\$1 \$5
6654		ADDI	\$1 1	6687	ADDI	\$1 2048
6655		EXCH	\$3 \$1	6688	ADDI	\$1 -4
6656		ADD	\$6 \$3	6689	XOR	\$3 \$1
6657		ADDI	\$6 2	6690	XORI	\$6 2
6658		EXCH	\$7 \$6	6691	EXCH	\$6 \$3
6659		ADDI	\$6 -2	6692	ADDI	\$1 -1
6660		SUB	\$6 \$3	6693	EXCH	\$3 \$1
6661		EXCH	\$9 \$8	6694	ADDI	\$1 -1
6662		ADDI	\$9 3	6695	BRA	l_main_0
6663		EXCH	\$10 \$9	6696	ADDI	\$1 1
6664		XOR	\$11 \$10	6697	EXCH	\$3 \$1
6665		EXCH	\$10 \$9	6698	ADDI	\$3 1
6666		ADDI	\$9 -3	6699	ADDI	\$3 1
6667	loadMetAdd_304_i:	EXCH	\$9 \$8	6700	EXCH	\$6 \$3
6668		XOR	\$8 \$7	6701	XORI	\$7 1
6669		ADD	\$6 \$3	6702	EXCH	\$6 \$7
6670		ADDI	\$6 2	6703	XORI	\$7 1
6671		EXCH	\$7 \$6	6704	ADDI	\$3 -1
6672		ADDI	\$6 -2	6705	ADDI	\$3 -1
6673		SUB	\$6 \$3	6706	ADDI	\$1 1
6674	l_main_0_bot:	BRA	l_main_0_top	6707	EXCH	\$6 \$3
6675	start:	BRA	top	6708	XORI	\$6 2
6676		START		6709	XOR	\$3 \$1
6677		ADDI	\$4 6715	6710	ADDI	\$1 4
6678		XOR	\$5 \$4	6711	ADDI	\$1 -2048
6679		ADDI	\$5 10	6712	XOR	\$1 \$5
6680		XOR	\$7 \$5	6713	ADDI	\$5 -10
6681		ADDI	\$4 10	6714	XOR	\$5 \$4
6682		ADDI	\$4 -1	6715	ADDI	\$4 -6715
6683		EXCH	\$7 \$4	6716	FINISH	