Optimizing AST Node for JavaScript Compiler
A lightweight Interpreter for Embedded Device

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Abstract — Limited memory in mobile devices presents the bottleneck to execution speed. Abstract Syntax Tree (AST) could be a better option for mobile codes as it is compiled only once. Hence, to improve the execution speed of a mobile device, AST node should be designed in such a way that it would consume less memory and improve the execution speed. In this paper, we implement AST node optimization technique for a set of frequently used operators and statements on a JavaScript compiler, such as Identifiers, Function-calls, Dot-operator and If-then-else. The desired optimization is justified by experimental results.

Index Terms — AST node, JavaScript Compiler, Optimization

I. INTRODUCTION

In the Script Engine architecture, the compiler component generates the AST and symbol tables. The interpreter executes the AST tree with reference to the symbol table. The other possible alternative is that the compiler generates the byte-code. Traditional byte-code generation involves 2 stages of compilation. At first, it generates AST and then byte-code from the AST. Many times, it has been observed that the scripts are compiled but not executed. Considering the memory limitation of the mobile devices and the limitation of execution, it is preferable to generate AST node and execute as and when required rather than converting all AST nodes to respective byte-codes. The Script Compiler converts the script code into an equivalent representation called Abstract Syntax Tree (AST). The AST is a structured tree format of the source script containing different nodes, which represent different constructs of the language and the references to the symbol table entries. The process of creation of AST involves interactions with the Symbol Table Manager for creating Symbol Table and updating information in it. AST and Symbol Table are used by script interpreter to perform evaluation. AST forms an end result of the parser after evaluation of the grammar rules.

In this paper, we have addressed the problem of AST node optimization for a set of frequently used statements on a JavaScript compiler. We have ported, tested and verified our script engine with devices a) Moto RAZR v3 (brew 3.15), b) Qtopia (Linux OS), c) Samsung (Windows), and d) Nokia Series (Symbian OS). We have implemented a JavaScript engine as per the ECMA (European Computer Manufacturers Association)-Script specification and then integrated the same with a web browser. The performance and memory consumption of AST nodes for different operators and statements like identifier, dot-operator, if-then-else and function-call are observed. The memory consumption pattern of this structure with various Alexa sites have been taken into consideration and we have come up with another alternative structure, which if used, shall improve the memory consumption drastically. During implementation, we have attempted to optimize the size of the structure and have observed the improved performance of the Alexa top 10 sites. In this paper, we intend to discuss the problem of memory consumption of the AST structures for identifier, function call, dot-operator, if-then-else and devise solutions to reduce the memory occupied by them. In the AST node, identifiers are represented as unary nodes; function calls and dot operators as binary nodes and if-then-else as ternary node.

II. RELATED WORK

Authors in [1] propose an Architecture Description Language (ADL)-driven method for accurately capturing a wide range of programmable architectures and thereby generating efficient compilers. A compilation framework for code reduction in embedded applications presented in [2] uses a heuristic, leading to a dual instruction set which
is space-efficient. A compiler optimization problem is addressed to enhance energy efficiency of Register File (RF) protection with respect to a number of embedded applications [3]. A dynamic code mapping technique is presented by authors in [4], which uses a heuristic algorithm that creates an efficient Function-to Space mapping with a given code size in the local storage, thereby increasing the speedup. A compiler technique based on inter-procedural code analysis for reduction of vulnerability of RF to soft errors is proposed in [5], which uses a heuristic algorithm in order to optimize overhead reduction, consequently leading to an effective reduction of code size overhead. Simultaneous Determination of Regions and Function-to-Region mapping for scratchpad memories (SRDM), a fully automated, dynamic, code overlaying technique based on pure compiler analysis for energy reduction for on-chip scratchpad memories in embedded systems, is detailed in [6], which is capable of reducing total energy consumption, consequently reducing the energy of the memory subsystem as a whole. Authors in [7] present a Compiler-in-the-Loop (CIL) framework for Design Space Exploration (DSE) processor architecture that comprises of an optimizing compiler, an instruction set simulator and a cycle-accurate simulator for earlier estimation of performance, power and code size. A customizable re-target able compiler framework is presented in [8] that is capable of determining phase-ordering between different transformations dynamically as per the resource availability and program region characteristics. Here, authors conduct experiment with ordering If-Conversion, a predicted execution technique and Speculative code motion, and the results demonstrate the flexibility of ordering of the transformations while compiling. The compiler approach to optimization of memory hierarchy along with a set of challenges to it is addressed by the authors in [9]. Authors in [10] focus on two tasks to instruction selection phase: first is to find an efficient algorithm which would generate an optimal instruction sequence and second is the automatic generation of instruction selection programs.

III. AST NODE AND REPRESENTATION

A. AST Node

The Script Compiler converts the script code into an equivalent representation called Abstract Syntax Tree (AST). The AST is a structured tree format of the source script containing different nodes that represent different constructs of the language. AST forms an end result of the parser after evaluation of the grammar rules.

The syntax analyzer creates the Abstract Syntax tree (AST) using bottom-up approach. This approach involves creation of leaves of the tree and then the created nodes are linked to form a structured tree. An AST node represents the type of operation that is allowed on its children and the structure of the children. Depending on the operation supported, the AST node is categorized as unary, binary or ternary. In this paper, we mainly focus on optimization of AST node for an identifier (unary node), dot operator (binary node), function call (binary node) and if-then-else (ternary node) statements. The following is the structure of a typical AST node.

```
typedef struct _ast
{
    E_TYPE eNodeType ;
    void *pBranch ;
} AST;
```

Here, eNodeType specifies the node type, where as pBranch is a pointer which contains the data of that node type.

For an identifier, the eNodeType is “E_IDENTIFIER_NODE” and the pBranch points to the structure of an identifier. An identifier structure contains the symbol reference and the symbol table entries.

Example of binary: For a function call, the eNodeType is “E_FUNCTION_CALL” and the pBranch points to the structure of a binary node, function. Function name and the arguments are the two parameters for the function call. To represent the AST node for the function call, the function name is in left hand site of the AST node which is an identifier node and arguments are in right hand site of the AST node which is the identifier list node.

For a dot operator, the eNodeType is “E_DOT_TOK” or “E_DOT_TOK_LIST” and the pBranch points to the structure of a binary node. Object name and its property name are the two parameters for the dot operator. AST node for dot operator is represented as an identifier appearing to the left of the dot operator which is the object and another identifier appearing to its right which is the property of that object. Thus, to specify the property of an object, a dot operator is used in between two identifiers, i.e. a.b, where “a” is an object and “b” is its property. In order to specify the property of an object, which is a property of another object, multiple dots can be used between the identifiers, i.e. a.b.c, where “c” is a property of object “b” and “b” is a property of object “a”. For single dot operator, eNodeType is “E_DOT_TOK”, and for multiple nodes, eNodeType is “E_DOT_TOK_LIST”. Similarly other binary nodes are conditional statement, mathematical statements (+, -, *, /) etc.

Example of Ternary: For if-then-else, the eNodeType is “E_IF_THEN_ELSE” and the pBranch points to the structure of a ternary node, if-then-else. Conditional statement, true statements and the false statements are the parameter of if-then-else. To represent the AST node for the if-then-else, the conditional statements are in child-1 of the AST node which are binary nodes or list of binary nodes, the true and false statements are child-2 and child-3 of the AST node which are either unary, binary, ternary or the list of those nodes.

B. Identifier node, Binary Node and Ternary Node

A variable is an identifier, whose name is stored in the string table and its value in the symbol table. The node representing the identifier contains pointer to the entry in the string table as well as a reference to the symbol table entry. The process of creation of AST for an identifier involves interactions with the string table for getting the
symbol reference and symbol table entries for updating information in it.

typedef struct _Identifier
{
    void *vNameRef;
    void *vRefSymTab;
} IDENTIFIER;  (Size: 8 bytes)

The symbol table provides an interface to store the data pertaining to a symbol and whenever a lookup is required an appropriate reference to the symbol table entry is returned back to the caller. It is used to reference the global scope by default and whenever the control enters a new scope or local scope logically (i.e when function is encountered), the symbol table is updated with the current information of the function name, the reference of the function points to a newly created scope. The handle is assigned with the new scope reference. The symbol table is responsible for managing the storage of the symbols encountered during the process of compilation and interpretation of the scripts.

Other categories include Binary and Ternary, which will contain pointers to one, two and three separate AST nodes respectively, as given below:

typedef struct _Binary
{
    AST *pLeft;
    AST *pRight;
} BINARY;  (Size: 8 bytes)

typedef struct _Ternary
{
    AST *pC1;
    AST *pC2;
    AST *pC3;
} TERNARY;  (Size: 12 bytes)

The function call and dot operators are represented with binary nodes while if-then-else operator with ternary node.

### IV. Problem Description

The Script Compiler contains a unit called the Lexical Analyzer (LA) that interacts with the Syntax Analyzer or parser and provides the tokens with reference to symbol table when requested. The LA generates tokens for input buffer provided by the parser. Yacc tool parses the input grammar and generates source code for parsing.

#### A. Identifier Node

In java script, when a variable is declared with the keyword "var", then script compiler creates an identifier node and resolves it by creating a symbol table entry either in the global scope or in the local scope depending on the context of declaration. If it is declared inside a function, then it creates a symbol table entry in local scope else in global scope. Many times the variables are not declared with “var” keyword or global variables are used inside the local function and these are resolved at the time of execution. These are known as unresolved identifier nodes. In order to improve the speed of the execution, it is required to reduce the memory of the identifier node thereby optimizing the structure of the node. Currently, for a single identifier node, 12 bytes are used (Table II). We can reduce the size of identifier node to 8 bytes.

During Compilation, once Lex gets the identifier token, it searches the string reference from the string table; Yacc gets symbol table reference from symbol table and generates an identifier node with string reference and symbol table reference. If particular symbol is not added to the symbol table in that scope (global or local), the symbol table reference is NULL and known as unresolved identifier. The unresolved identifier would be
resolved at the time of interpretation by replacing string table reference with symbol table entry. As many times the variables are in unresolved state, the unused NULL pointers are huge in number [Table III, Fig.1].

### TABLE III
**STATISTICS OF REPORT OF UNRESOLVED IDENTIFIER NODE**

<table>
<thead>
<tr>
<th>Alexa Sites</th>
<th>Unresolved Identifier Node</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Global Scope</td>
</tr>
<tr>
<td>CNN</td>
<td>439</td>
</tr>
<tr>
<td>MSN</td>
<td>67</td>
</tr>
<tr>
<td>EBAY</td>
<td>612</td>
</tr>
<tr>
<td>AMAZON</td>
<td>56</td>
</tr>
<tr>
<td>REDIFF</td>
<td>57</td>
</tr>
<tr>
<td>NDTV</td>
<td>105</td>
</tr>
<tr>
<td>YATRA</td>
<td>165</td>
</tr>
<tr>
<td>ALIBABA</td>
<td>317</td>
</tr>
<tr>
<td>APPLE</td>
<td>1209</td>
</tr>
</tbody>
</table>

### B. Dot Operator Node

The Dot operator feature is used widely in java script. During Compilation, once Lex gets the dot operator, it returns TOK_DOT and the next token will be an identifier. Then Lex looks up the string reference of the Identifier from the string table. Yacc creates an Identifier node using string table reference only without the Symbol Table reference. The identifier node present on the right hand side of the DOT operator is used for lookup from the Object using the string reference only and not the symbol table reference during Interpretation. Hence the symbol table reference which is not used can be removed for optimization.

Script interpreter interprets the dot operator from right to left unlike binary operator. It starts evaluation from left which is an object and then the property. To make it easy for interpretation, it is required to restructure the dot operator.

### C. Function Call and If-then-else Node

Function calls and if-then-else are also frequently used in java script. Minimum 28 bytes are being used for a function call with a single argument and 16 bytes are used for if-then else node (Table II). In order to improve the speed of execution as well as to increase the speed of script engine, it is required to reduce the memory of the function call node and if-then-else node. Very often, the functions are called without the arguments and if-then statement is used without else [Table IV, Fig.2].

### TABLE IV
**STATISTICS OF REPORT OF DOT OPERATOR, IF-WITHOUT-ELSE, FUNCTION CALL WITHOUT ARGUMENTS**

<table>
<thead>
<tr>
<th>Alexa Sites</th>
<th>Dot operator, Without Else and Function call without Arguments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dot operator Without Else Function call Without Argument</td>
</tr>
<tr>
<td>CNN</td>
<td>5086 604 71</td>
</tr>
<tr>
<td>MSN</td>
<td>4416 859 256</td>
</tr>
<tr>
<td>EBAY</td>
<td>6080 453 18</td>
</tr>
<tr>
<td>AMAZON</td>
<td>1978 1075 58</td>
</tr>
<tr>
<td>REDIFF</td>
<td>113 30 2</td>
</tr>
<tr>
<td>NDTV</td>
<td>945 936 126</td>
</tr>
<tr>
<td>YATRA</td>
<td>5041 524 26</td>
</tr>
<tr>
<td>ALIBABA</td>
<td>5583 758 67</td>
</tr>
<tr>
<td>APPLE</td>
<td>8274 1019 27</td>
</tr>
</tbody>
</table>

Figure 1. Statistics of memory report for unresolved identifier node

Figure 2. Statistics of memory report for Dot operator, if-without-else and function call without arguments
V. PROPOSED SOLUTIONS

A. Identifier Node

If the identifier is already resolved, it is not required to keep the string table reference as it is also available in the symbol table reference. Similarly, for the identifier, which is not resolved, the symbol table reference is not required as it would be resolved during interpretation. As shown in Table III, many unresolved identifiers are being used in the web page and their symbol table references are NULL. In order for optimization, the NULL pointer, 4 bytes in size, can be removed from the identifier node.

In this proposed solution, there are two node types instead of one node type (E_ATYPE_IDENTIFER). These are:

- **E_ATYPE_IDENTIFER_RESOLVED**: If the identifier is in the symbol table, then the node type is E_ATYPE_IDENTIFER_RESOLVED and it will contain the address of the symbol table reference only.

- **E_ATYPE_IDENTIFER_NOTRESOLVED**: If the identifier is not in the symbol table, then the node type is E_ATYPE_IDENTIFER_NOTRESOLVED and it will contain the address of the string table reference only. During the interpretation, interpreter will resolve that identifier and replace the string reference with symbol table reference. With this approach, memory consumed by an identifier can be reduced from 12 bytes (Table II) to 8 bytes (Table V), and the interpreter task can be reduced as well. During the time of interpretation, it will be easier for the interpreter to take the decision whether to look up an identifier or not.

B. Dot Operator Node

The behavior of the dot operator is similar to that of the binary node. An object appears to the left of the Dot operator and the property of that object to the right of it (e.g. a.b). The number of binary nodes will increase if the dot operators are used in between two or more identifiers (e.g. a.b.c). Dot operators are used quite frequently. As it can be observed from Table II, a single dot operator occupies 24 bytes, where the property of that object is an identifier and the symbol table reference is NULL.

In this proposed solution, there are two node types instead of E_DOT_TOK and E_DOT_TOK_LIST. These are:

- **E_ATYPE_DOT_LEAF**: If the dot operator is used between two identifier nodes then the left hand identifier node will have the symbol table reference if it is resolved, else if not resolved, it will have a string table reference and the right hand operator will hold only the string table reference.

- **E_ATYPE_DOT_NOT_LEAF**: For more than two identifiers, the left hand operator would have another AST node which is either E_ATYPE_DOT_LEAF node or E_ATYPE_DOT_NON_LEAF node and the right hand identifier has the string table reference only.

C. Function Call Node

Functions are called with or without the arguments. Based on this behavior, function call node can be divided into two types.

- **E_ATYPE_FUNCTION_CALL_WITHOUT_ARGS**: If the function call is without any argument then the left hand will be an AST node (E_ATYPE_DOT_LEAF or E_ATYPE_DOT_NON_LEAF or E_ATYPE_IDENTIFER_RESOLVED or E_ATYPE_IDENTIFER_NOTRESOLVED).

- **E_ATYPE_FUNCTION_CALL_WITH_ARGS**: It is the same as function call node, explained above. (Table II)

D. If-Then-else Call Node

- **E_ATYPE_IF_WITHOUT_ELSE**: In the “if-then-else” statement, if there is no “else” statement, it will be represented as binary node instead of ternary node.

- **E_ATYPE_IF_WITH_ELSE**: It is the same as if-then-else node, explained above. (Table II)

### TABLE V

<table>
<thead>
<tr>
<th>Operator Description</th>
<th>Memory Size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Identifier</strong></td>
<td></td>
</tr>
<tr>
<td>E_ATYPE_IDENTIFER_RESOLVED</td>
<td>4</td>
</tr>
<tr>
<td>E_ATYPE_IDENTIFER_NOTRESOLVED</td>
<td>4</td>
</tr>
<tr>
<td>vNameRef/ vRefSymTab</td>
<td>4</td>
</tr>
<tr>
<td><strong>Function Call</strong></td>
<td></td>
</tr>
<tr>
<td>E_ATYPE_FUNCTION_CALL_WITHOUT_ARGS</td>
<td>4</td>
</tr>
<tr>
<td>Identifier Node</td>
<td>8</td>
</tr>
<tr>
<td>E_ATYPE_FUNCTION_CALL_WITH_ARGS</td>
<td>4</td>
</tr>
<tr>
<td>Identifier (Function name)</td>
<td>8</td>
</tr>
<tr>
<td>Identifier (1 parameter)</td>
<td>8</td>
</tr>
<tr>
<td><strong>DOT Operator</strong></td>
<td></td>
</tr>
<tr>
<td>E_ATYPE_DOT_LEAF</td>
<td>4</td>
</tr>
<tr>
<td>pLeft -&gt; vASTNode</td>
<td>8</td>
</tr>
<tr>
<td>pRight -&gt; vNameRef</td>
<td>4</td>
</tr>
<tr>
<td>E_ATYPE_DOT_NON_LEAF</td>
<td>4</td>
</tr>
<tr>
<td>pLeft -&gt; vASTNode</td>
<td>-</td>
</tr>
<tr>
<td>pRight -&gt; vNameRef</td>
<td>4</td>
</tr>
</tbody>
</table>

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In this paper, we address the problem of optimization of the java script AST node in order to reduce the run-time memory requirements, with a set of with devices: a) Moto RAZR v3(brew 3.15), b) Qtopia (Linux OS), c) Samsung windows, and d) Nokia Series (Symbian OS ) keeping in view that mobile devices are constrained with limited memory resources. The said optimization is carried with most frequently used in java script identifiers, function calls, dot operators and if-then-else statements. The experimental results justify the intended optimization [Table VI, Fig.3]. It can be useful for script engines.

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