Faulty Slice Distribution using Complexity Estimation for Debugging in Parallel

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ABSTRACT
In this paper we propose a technique to distribute faulty slices among available n debuggers for simultaneous debugging. We present a three level model to distribute debugging task efficiently among debuggers by (a) estimating capacity of task to be allocated to an individual debugger (b) measuring similarity and assigning priority to each faulty slice to minimize redundancy of debugging task(c) uniformly distributing faulty slices by arranging them in task queues. For this we present an algorithm and an example to prove effectiveness and efficiency of the presented approach.

General Terms
Debugging, fault localization, optimization, software testing.

Keywords
Clustering, debugging, fault localization, optimization, software testing.

1. INTRODUCTION
Debugging is the most expensive, time consuming and dominantly manual process for software developers. The cost related to debugging is measured mostly on two parameters: (a) manual labor and (b) time required to discover and correct bugs to produce a failure free program. The primary reason for such a high cost of debugging is manual effort required to localize and remove a fault and time consumed in producing failure free software. For an efficient debugging process developers always try to find a good trade-off between the two. Among all debugging activities, fault localization is among the most expensive [7].

When software fails it is usually due to more than one cause. At the time of failure debuggers are not aware of number of causes one failure might have. Thus, usually one-bug-at-a-time debugging approach is carried out in a sequential manner to locate a fault and then to fix it. In this approach debugger might utilize data from failed test cases and apply a fault localization technique where one bug is targeted at a time. After localizing and fixing fault program is retested, which might lead to another failure and cycle gets repeated till program becomes failure free.

However, when there can be multiple debuggers available for debugging task then we can create more specialized test suites based on fault focusing clusters and distribute debugging task. By distributing debugging task we can save time and hence make debugging activity less expensive. [11] have presented a new mode of debugging technique that provides a way for multiple developers to debug simultaneously a program for multiple faults by automatically producing specialized test suites for targeting individual faults. This technique has been termed as parallel debugging. Debugging in parallel reduces time required to debug multiple faults in a program. It includes distributing program into many executable faulty slices which can be debugged independently. Multiple debuggers are then allocated these individual slices for independent de-bugging.

In this research we propose a new debugging technique to distribute faulty slices among available n debuggers for simultaneous debugging. For this we present a three tier model to estimate amount of work related to a slice for efficient distribution by (a) estimating complexity of each slice (b) calculating upper limit of a task to be allocated to a debugger (c) measuring similarity and assigning priority to each faulty slice to minimize redundancy of debugging task.

2. RELATED WORK
Much of recent work in debugging has been focused on fault localization as it is one of most expensive parts of debugging practice. There are various coverage-based fault localization techniques aiming at identifying executing program elements. Among them some use coverage in-formation provided by test suites to locate faults. Such techniques [14, 8, 9, 3] typically instrument and execute program with test suite to gather runtime information. Other faults localization techniques are: χSlice [5] which collects coverage from a failed test run and a passed test run and set of statements executed only in failed test run are reported as likely faulty statements, Nearest Neighborhood (NN) [12] is an extension of [5] which features an extra step of passed test run selection. Tarantula [10] defines a color scheme to measure correlation i.e. it searches for those statements whose coverage has a relatively strong (but not necessarily strict) correlation with program failures. The empirical comparison of [8] compares Tarantula with χSlice and NN and their results shows that Tarantula performs best among them. Statistical debugging [2,4] instruments predicates in program and locates faults by comparing evaluation results of predicates in failed test runs with those in all test runs whereas Delta debugging [6,1] grafts values from a failed test run to a passed test run. However cost of repeating trials can be expensive [15] but it has been shown to be useful in revealing many real world faults. The results [8] show that when multiple test runs are available,

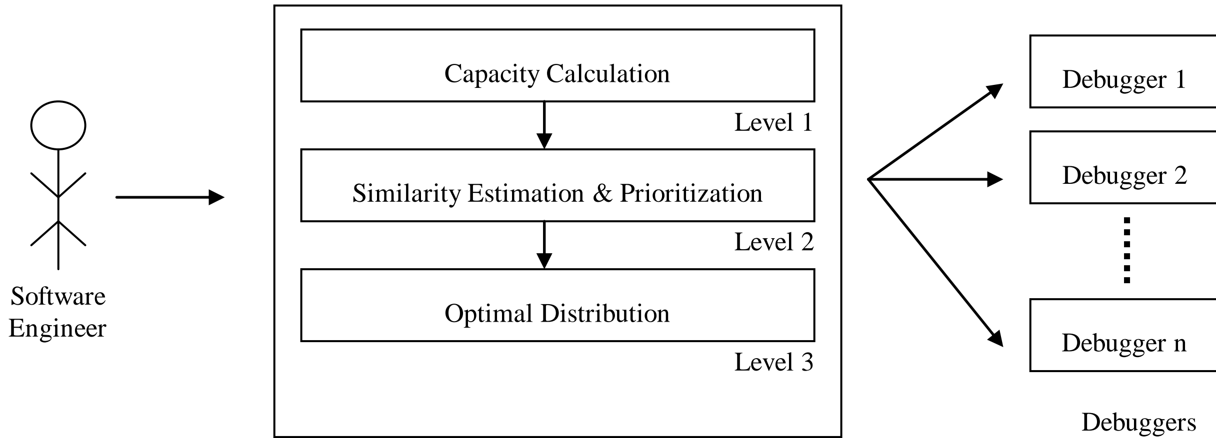

Figure 1. Three level distribution model

performance of Coverage Based Fault Localization (CBFL) is better than that of delta debugging.

3. PROPOSED APPROACH

Fault localization is costly as well as time consuming. The primary reason for such a high cost of debugging is manual effort required to localize and remove a fault and time consumed in producing failure free software. We present an approach that will help in distributing task equally among available debuggers thereby minimizing cost in terms time. The whole process is divided into 3-level distribution hierarchy as shown in Fig 1.

The process starts with Capacity Calculation level. It is a complex level made up of three pre-processes. It starts with generating faulty slices using fault localization technique given in [10] and then combines these faulty slices to generate different clusters using [11]. Once the faulty slices are combined it computes complexity for each slice using our technique of complexity estimation given in [13].

Once complexity for each slice is computed it starts with calculation of capacity of task queue where a task queue is a queue which will contain faulty slices to be allocated to debuggers. The maximum number of faulty slices a queue can hold is given by following formula:

$$\textit{Capacity of a task queue } (Cq) = \text{Max}\left(\frac{\sum_{i=0}^{n} C_i}{\textit{number of debuggers}}, \textit{Maximum complexity of a faulty slice} \right) \quad (1)$$

where C_i is the complexity of ith faulty slice and there are n faulty slices in total.

The second level is a two stage process. Firstly it considers results of level 1 and arranges faulty slices in decreasing order of their complexities. This will help in efficiently selecting faulty slices for adding in a task queue. Secondly it calculates similarity between faulty slices using a two dimensional matrix (M). This is done to club similar slices to minimize redundant debugging work done by two or more debuggers. In this matrix we store similarity between two slices i and j such that:

$$M_{i,j} = \text{the similarity between faulty slices } (i, j) \quad (2)$$

In the last phase we optimally distribute faulty slices among debuggers for debugging using following rules:

- Select the first faulty slices from list arranged in decreasing order of their complexities as first slice of task queue.
- For subsequent faulty slice we start from last element i.e. unallocated faulty slice with minimum complexity in the priority list as it minimizes number of tests which needs to be performed.

$$\sum_{i=0}^{m} C_i + C_x < Cq \quad (3)$$

Where Fi is the complexity of ith faulty slice in the current task queue and m faulty slices have already been selected. Cx is the complexity of the current faulty slice being considered and Cq is the capacity of task queue.

- If there are more than one faulty slices that fit the above criterion then one which has maximum similarity to last selected faulty slice (Fm) is selected.

4. ALGORITHM

```
F_i is i^th faulty slice
C_i is complexity of i^th faulty slice
max = C_1
for i from 1 to n
        if (C_i> max)
                max = C_i
sum = 0
for i from 1 to n
        sum = sum + C_i
x = sum / m
if(x > max)
        Cq = x
else
        Cq = max
for i from 1 to n
        addtoList(S, F_i)
SortList(F_i) // Sort the list in non-increasing order of complexity
j = 1
for i from 1 to m AND empty(S) = FALSE
        while (Complexity(Q_i) < Cq )
                if (Q_i is empty)
                        enqueue(Q_i, removeFromlist(S))
                else
                        C = lastElementof(S)
                        P = endof(Q_i)
                        sim = 0
                        while( C != NULL)
                                if( (Complexity(Q_i) + Complexity(C))< Cq)
                                        if(similarity(P,C) >sim)
                                                Z = C
                                                sim = similarity(P,C)
                                else
                                        break; //Break out of while loop
                                C = C→prev
                        if ( Z != NULL )
                                removeFromList(S,Z)
                                enqueue (Q_i, Z)
                        else
                                break
while(empty(S) = FALSE)
        TF = RemoveFirstElement(S)
        min = ∞
        for i from 1 to m
                if(Complexity(Q_i ) < Cq )
                        if (Complexity(Q_i) + Complexity(TF)< min)
                                min = Complexity(Q_i) + Complexity(TF)
                                k = i
        enqueue (Q_k, TF)
```

Figure 2. Algorithm

5. EXAMPLE

To illustrate the process consider a program in Figure3. Figure 4(a),(b),(c),(d) show its corresponding clustered slices after applying fault localization and clustering technique of [10, 11]. Next step our algorithm computes complexity for each faulty slice using [13]. Table 1 shows the results for complexity estimation. Based on the data of Table 1 each slice is assigned a priority to it. This data is arranged in descending order of their priorities for efficient selection of faulty slices for adding in a task queue. Table 2 shows the results after assigning priority to faulty slices. Once the priority is computed a two dimensional similarity matrix is created as shown Table 3 results of which are used in calculating capacity for task queue according to the formula given in (1) and shown in Table 4. Fig 5 represents the sketch of task queue using the data of Table 4.

```
if(first-65 > 8 || second - 65 >  9);
else if(web[first-65][second-67])
{
printf("\nDirect connection from %c to %c
",first,second);
con=1;
}
else
{
for(i=0;i<10;i++)
{
if (web[first-65][i])
{
if(web[i][second-65]&&con!=1)
{
printf("\nConnection through %c->%c-
>%c",first,i+64,second);
con=0;
}
else
{
if(con!=1)
{
for(j=0;j<9;j++)
{
if((i!=j)&&(i!=first-65)&&(web[i][j]&&web[j][second-
65])&& con!=1)
{
printf("\nConnection through %c->%c->%c-
>%c",first,i+65,j+65,second);
con=1;
}
}
}
}
}
}
}
if(con==0)
{
printf("\nBAD PAGE!");
}
```

Figure 3. Example program

if(first-65 > 8 || second - 65 > 9);
}
if(con==0)
{
printf("\n BAD PAGE");
}

(a)

if(first-65 > 8 || second - 65 > 9);
else if(web[first-65][second-67])
{
{
for(i=0;i<10;i++)
{
if (web[first-65][i])
{
if(web[i][second-65]&&con!=1)
{
{
if(con!=1)
{
for(j=0;j<9;j++)
{
if((i!=j)&&(i!=first-5)&&(web[i][j]&&web[j][second-65])&& con!=1)
{
}
}
}
}
}
}
if(con==0)
{
printf("\nBAD PAGE!");
}

(b)

```
if(first-65 > 8 || second - 65 >  9);
else if(web[first-65][second-67])
{
printf("\nDirect connection from %c to %c ",first,second);
con=1;
}
else
if(con==0)
```

(c)

```
if(first-65 > 8 || second - 65 >  9);
else if(web[first-65][second-67])
{
{
for(i=0;i<10;i++)
{
if (web[first-65][i])
{
if(web[i][second-65]&&con!=1)
{
printf("\nConnection through %c->%c->%c",first,i+64,second);
con=0;
}

}
}
}
if(con==0)
{
printf("\nBAD PAGE!");
}
```

(d)

Figure 4. (a), (b), (c), (d). Faulty Slices

Table 1. Complexity estimation of faulty slices

Slice	**Slice 2**	**Slice 4**	**Slice 3**	**Slice 1**
Complexity	18.52	17.18	6.93	4.35
Priority(P_i)	P_1	P_2	P_3	P_4

Table 2. Results of priority assignment to each faulty slice

	Complexity
Slice 1	4.35
Slice 2	18.516667
Slice 3	6.9333333
Slice 4	17.183333

Table 3. Similarity matrix

Percentage Similarity				
	Slice 1	**Slice 2**	**Slice 3**	**Slice 4**
Slice 1	100	22.222222	27.27	24
Slice 2	22.222222	100	12.9	54.839
Slice 3	27.27	12.9	100	16
Slice 4	24	54.839	16	100

Table 4: Task queue

	TQ1	**TQ2**
	Slice 2	Slice 4
	Slice 1	Slice 3
Total Complexity	22.86667	24.11667

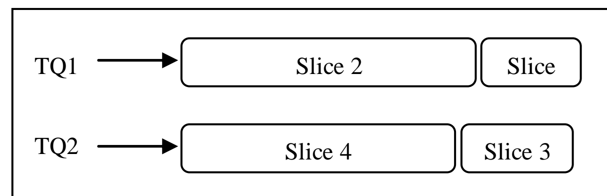

Figure 5. Sketch of task queues

In the presented example we can observe that by measuring complexity, similarity and priority of faulty slices we have successfully distributed these slices equally among debuggers. The distribution presented is also likely to give independent faulty slices to the debuggers avoiding redundancy of debugging task.

6. CONCLUSION

In this paper we have presented an efficient approach for distributing task among debuggers. The entire process is divided into three levels. In first level our algorithm calculates capacity of a task queue by analyzing clustered faulty slices and then arranges these slices according to their priority. Once this data is

arranged it computes the similarity matrix for clustered slices which is a two dimensional matrix. Based on this data slices are distributed among available debuggers. This helps in reducing two important tasks of debugging namely cost and time by (a) estimating complexity for uniform distribution (b) minimizing redundancy by allocating more similar slices to one debugger using similarity matrix. Finally we presented an example to prove efficiency and effectiveness of our approach.

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