Estimation of Reliability Allocation on Components Using a Dynamic Programming

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Abstract
In this paper, we used Dynamic Algorithm for the purpose of allocation of Reliability of components in a software product Design phase. The reliability and cost allocation can be used to solve the optimal allocation problems in simple systems as well as applicable to complex systems. Our experiment show near optimal solution to the problem of selecting the component and comprising the software can be obtained with lower cost. We observed different sizes of components and their reliability and cost in a structure. Finally we gave the importance of how to select reliability and cost of each component in architecture-based software. 

Keywords: software architecture, software reliability, Reliability Allocation, Reliability Estimation, Dynamic Programming

1. Introduction
Software system is used in everywhere on our daily lives. Suppose a failure can be occurred during the operation of software can lead to economic loss and waste of time and may even cause loss of human lives also. If the unreliable software is identified in the early stage, loss may be small. Therefore unreliable software is not acceptable and it should be identified in the beginning of the software development. If it is not identified initial stage and later the defects found, the higher the cost that needs to paid for them.

Software Reliability is one of the very important and quality attributes of software since it quantifies software failures during the development process. If the higher level of Reliability of software can definitely result in more development cost. In practical Engineering, software project managers are required to estimate the cost needed to complete the development of software system is taking into account the required level of reliability is provided or not. So many software reliability models had been proposed in the past decades to help the software managers and developers to analyze and design the system. The main constraint in software development is maximizing reliability and minimizing cost.

In my previous paper estimation of reliability and cost relationship for architecture-based software paper gives the some idea about the development cost in before starting the implementation phase.

In this paper we explained design phase of each component reliability allocation in a small and large case software. 

Mainly in design phase we know the main constraints. First one is system size and second one is project structure. I am taking first one is system size. System size means number of components. The components may be depends on the size of the project structure.

The argument of this paper takes the following arrangement. Section 2 introduces software reliability allocation model. Section 3 depicts how to find out the optimal allocation method by using a dynamic programming algorithm. Section 4 illustrates the application of the algorithm proposed in section 3 and section 5 offers concluding remarks and directions.

2. Software Reliability Allocation Model

2.1 Software development cost minimization versus reliability allocation

In fact, it is impossible to develop the software reliability while dropping the software system development cost because they are two contradictory constraints. The pretended software development cost minimization can be considered from two facts of views. One is to find an
optimal reliability allocation method while achieving the
given reliability such that the development cost can be as
small as possible; the other is how to allocate the reliability
to each component on the premise of the given cost so that
the system reliability can be maximized. This paper
focuses on the former one.

Many systems are executed by using a set of interrelated
subsystems. Reliability allocation means fixing the
reliability among different subsystems so that the total
system development cost (including human, material
resources, development time and testing time etc) can be
minimized. Reliability allocation can be used to
arrangement with such kind of problem that the objective
is set prior to the solution. Generally the number of the
solution is more than one, as a result reliability allocation
is used to deal with the optimal problem with some
constraints.

3. Expending Dynamic Programming
Algorithm To Solve Reliability Allocation
Problem:

A software system with n components and the association
function F discussed above is known. The reliability-cost
coefficient α of each component and the specified system
reliability target R_obj is given.

The dynamic programming algorithm is as follows:

Step 1: Let S represent the reliability matrix \([r_1, r_2, \ldots, r_n]\),
T represent the cost matrix \([c_1, c_2, \ldots, c_n]\), δ be the
solving step length, \(I_i\) represent the matrix with one
column and n rows in which only the value of the ith
element is 1 and the rest are all 0. Assume \(S_0=[\text{maxr}, \text{maxr}, \ldots, \text{maxr}]\), \text{maxr} represents the maximized possible
reliability, for example 0.9999, which means the initial
reliability values of the components are all \text{maxr}.

Step 2: As for \(S_0\), \(T_0\) and \(C_0\) can be given by \(S_0\) and
system reliability \(R_0\) can be given by function F.

Step 3: If \(R_0<R_{\text{obj}}\) then stop and return. No solutions.

Step 4: Set \(R=0\);

Step 5: for \(i=1\) to \(n\)
  i) \(S'=S_0- I_i \times δ\);
  ii) With regard to \(S'\), Generate reliability \(R'\) with
the function F, \(T'\) with (7), total cost \(C'\)
  iii) \(ΔC=C_0-C'\); \(ΔR=R_0-R'\);
  iv) if \(R'\geq R_{\text{obj}}\) and \(ΔC/ΔR>\text{Rate}\) then Set
\(\text{Rate}=ΔC/ΔR\), \(R=R'\), \(S=S'\), \(C=C'\), \(T=T'\);

Step 6: if \(R_0<R\) then set \(S_0=S; R_0=R; C_0=C; T_0=T;\)
return to step 4

Where reliability allocation result \(S_0\) is the reliability of
each component. \(R_0\) and \(C_0\) are the corresponding system
reliability and expected system development cost. \(T_0\) is the
expected development cost allocated to each component.
Notice from the above that prerequisite to the correctness
of the algorithm is that the decrease in reliability of one
component can result in that of the whole system and lower
the development cost. But that can be guaranteed in our
algorithm. The aim of step 5 iv) in the above algorithm is
to select an optimal component whose decrease in
reliability can result in the maximal cost/reliability
variation, which makes the single step programming
optimized so that optimal reliability allocation of the
ultimate system is guaranteed.

4. Example and Result

Here we choose a system with four independent
components \(r_1, r_2, r_3, r_4\). We assume that all the
components are essential to the system and their failures
are statistically independent. Therefore, the relationship
between the total system reliability \(r\) and its components’
reliability \(r_i\) (i=1, 2, 3, 4) can be stated as: \(r = F (r_1, r_2,
r_3,r_4) = r_1*r_2*r_3*r_4\) Suppose that the complexities of the
components are 0.35, 0.52, 0.74 and 0.91 respectively. In
order to minimize the system development cost and the
system reliability shall be no less than 0.94, how to
allocate the reliability to each component. Set the precision
of computing is 0.01.

Such a problem can be rewritten as:

\[
R = r_1*r_2*r_3*r_4 \leq 0.94
\]
\[
c_1 = - \frac{0.35}{\ln r_1}
\]
\[
c_2 = - \frac{0.52}{\ln r_2}
\]
\[
c_3 = - \frac{0.74}{\ln r_3}
\]
\[
c_4 = - \frac{0.91}{\ln r_4}
\]

Compute the values of parameters \((r_1, r_2, r_3, r_4)\)
with which the total cost \(C\) \((C = c_1+c_2+c_3+c_4)\) is
minimized. With respect to each component, we compute
the cost with the reliability from 0.91 to 0.99 (increment is
0.01) according to the reliability/cost function model in the
data set as shown in Table 1.

According to the algorithm above, set initial state \(S_0 = [0.99, 0.99, 0.99, 0.99]\). Accordingly, \(T_0 = [34.82, 51.74,
73.63, 90.54]\), \(\delta=0.01\), and the system cost \(C_0=34.82+51.74+73.63+90.54 = 250.73\), system reliability
\(R_0=0.99 * 0.99*0.99*0.99 = 0.96\).

Set \(i=1, 2, 3, 4\) then compute separately with different
value:

1) \(S' = S_0 - [0.01, 0, 0, 0] = [0.98, 0.99, 0.99, 0.99],\)
R' = 0.9, T' = [17.32, 51.74, 73.63, 90.54], C' = 233.23  
ΔC = 17.4, AR = 0.01, AC/AR = 1750

2) S' = S0 – [0, 0.01, 0, 0] = [0.99, 0.98, 0.99, 0.99], R' = 0.94, T' = [34.82, 25.74, 73.63, 90.54], C' = 224.73  
ΔC = 26, AR = 0.01, AC/AR = 2600

3) S' = S0 – [0, 0.01, 0, 0] = [0.99, 0.99, 0.98, 0.99], R' = 0.95, T' = [34.82, 51.74, 36.63, 90.54], C' = 213.73  
ΔC = 37; ΔR = 0.01, AC/AR = 3700

4) S' = S0 – [0, 0, 0, 0.01] = [0.99, 0.99, 0.99, 0.98], R' = 0.95, T' = [34.82, 51.74, 73.63, 45.04], C' = 205.23  
ΔC = 45.5; ΔR = 0.01, AC/AR = 4550

Choose the optimal result 2), set S0 = [0.99, 0.98, 0.99, 0.99], continue to perform the same operation:

1) S' = S0 – [0.01, 0, 0, 0] = [0.98, 0.98, 0.99, 0.99], R' = 0.94, T' = [17.32, 25.74, 73.63, 90.54], C' = 207.23  
ΔC = 43.5, AR = 0.01, AC/AR = 4350

2) S' = S0 – [0, 0.01, 0, 0] = [0.99, 0.97, 0.99, 0.99], R' = 0.94, T' = [34.82, 17.10, 73.63, 90.54], C' = 216.09  
ΔC = 34.64, AR = 0.01, AC/AR = 3464

3) S' = S0 – [0, 0.01, 0, 0] = [0.99, 0.98, 0.98, 0.99], R' = 0.94, T' = [34.82, 25.74, 73.63, 90.54], C' = 187.73  
ΔC = 63; ΔR = 0.01, AC/AR = 6300

4) S' = S0 – [0, 0, 0, 0.01] = [0.99, 0.98, 0.99, 0.98], R' = 0.94, T' = [34.82, 25.74, 73.63, 45.04], C' = 179.23  
ΔC = 71.5; AR = 0.01, AC/AR = 7150

Choose the optimal result 3), set S0 = [0.99, 0.98, 0.99, 0.99], continue to perform the same operation:

1) S' = S0 – [0.01, 0, 0, 0] = [0.98, 0.98, 0.99, 0.99], R' = 0.94, T' = [17.32, 51.74, 73.63, 90.54], C' = 196.23  
ΔC = 54.5, AR = 0.01, AC/AR = 5450

2) S' = S0 – [0, 0.01, 0, 0] = [0.99, 0.98, 0.98, 0.99], R' = 0.94, T' = [34.82, 25.74, 36.63, 90.54], C' = 187.73  
ΔC = 63, AR = 0.01, AC/AR = 6300

3) S' = S0 – [0, 0.01, 0, 0] = [0.99, 0.99, 0.97, 0.99], R' = 0.94, T' = [34.82, 51.74, 24.30, 90.54], C' = 201.4  
ΔC = 49.33; ΔR = 0.01, AC/AR = 4933

4) S' = S0 – [0, 0, 0.01] = [0.99, 0.99, 0.98, 0.98], R' = 0.94, T' = [34.82, 51.74, 36.63, 45.04], C' = 168.23  
ΔC = 82.5; AR = 0.01, AC/AR = 8250

Choose the optimal result 4), set S0 = [0.99, 0.99, 0.99, 0.98], continue to perform the same operation:

1) S' = S0 – [0.01, 0, 0, 0] = [0.98, 0.99, 0.99, 0.98], R' = 0.94, T' = [17.32, 51.74, 73.63, 45.04], C' = 187.73  
ΔC = 63, AR = 0.01, AC/AR = 6300

2) S' = S0 – [0, 0.01, 0, 0] = [0.99, 0.98, 0.99, 0.98], R' = 0.94, T' = [34.82, 25.74, 73.63, 45.04], C' = 179.23  
ΔC = 71.5; AR = 0.01, AC/AR = 7150

3) S' = S0 – [0, 0.01, 0, 0] = [0.99, 0.99, 0.98, 0.98], R' = 0.94, T' = [34.82, 51.74, 73.63, 45.04], C' = 168.23  
ΔC = 82.5; AR = 0.01, AC/AR = 8250

4) S' = S0 – [0, 0, 0.01] = [0.99, 0.99, 0.99, 0.97], R' = 0.94, T' = [34.82, 51.74, 73.63, 29.88], C' = 190.07  
ΔC = 60.66; ΔR = 0.01, AC/AR = 6066

5.Conclusion

Software reliability allocation for SDLC shows an important role during software product design phase and implementation phase which has close relationship with software modeling and cost evaluation. We formulated an architecture-based approach for modeling software reliability optimization problem, on this basis a dynamic programming algorithm has been proven in this paper which can be used to allocate the reliability to each component so as to minimize the cost of designing software while meeting the desired reliability objective. The result of our experiment show an optimal or approximate optimal solution to the problem of selecting the various sizes of components comprising software can be obtained with lower cost (a high reliability). The reliability and cost allocation model presented in this paper can be used to solve the optimal allocation problems in simple systems; it is also relevant in complex systems.

Acknowledgements

I state that in my research work, I am being guided immeasurably by Dr. K.Rajasekhar Rao, Professor, K.L.UNIVERSITY, Vaddeswaram, Guntur, and but for his guidance and support, I would not have reached this stage of submitting research paper, which is part of research, in my research work. I, therefore, acknowledge his guidance and support in this regard. I also acknowledge the support and encouragement given by my friends and well-wishers to pursue the Research work.

References


TABLE 1: COST AND RELIABILITY DATA SET

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