

# Why the Virtual Nature of Software Makes It Ideal for Search Based Optimization

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**Abstract.** This paper<sup>1</sup> provides a motivation for the application of search based optimization to Software Engineering, an area that has come to be known as Search Based Software Engineering (SBSE). SBSE techniques have already been applied to many problems throughout the Software Engineering lifecycle, with new application domains emerging on a regular basis. The approach is very generic and therefore finds wide application in Software Engineering. It facilitates automated and semi-automated solutions in situations typified by large complex problem spaces with multiple competing and conflicting objectives. Previous work has already discussed, in some detail, the advantages of the SBSE approach for Software Engineering. This paper summarises previous work and goes further, by arguing that Software Engineering provides the *ideal* set of application problems for which optimization algorithms are supremely well suited.

**Keywords:** SBSE, Search Based Optimization, Search Based Testing, Metaheuristic Search, Optimization Algorithms.

## 1 Introduction

We often speak of ‘Software Engineering’ without thinking too deeply about what it means to have a discipline of ‘engineering’ that considers the primary material to be ‘software’. By considering both the ‘engineering’ aspects of ‘Software Engineering’ and also the unique properties of ‘software’ as an engineering material, this paper makes an argument that search based optimization techniques are ideally suited to Software Engineering.

That is, though all other engineering disciplines have also provided rich sources of application for search based optimization, it is in its application to problems in Software Engineering that these techniques can find greatest application. This acts as a secondary motivation for the field of SBSE. The primary motivation

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<sup>1</sup> This paper is written to accompany the author’s keynote presentation at Fundamental Approaches to Software Engineering (FASE 2010). The talk provides an overview of SBSE and its applications and motivation. The paper focuses on the argument that the virtual nature of software makes it ideal for SBSE, since other aspects of SBSE mentioned in the FASE keynote have been covered by the author’s previous keynotes and invited papers.

for SBSE comes from the simple observation that these techniques do, indeed, apply well in other engineering disciplines and that, therefore, should we wish to regard Software Engineering as truly an engineering discipline, then it would only be natural to consider the application of search based optimization techniques. This form of advocacy for SBSE has been put forward by this and other authors before [CDH<sup>+</sup>03, HJ01, Har07b, Har07a, Har07c].

The acceptance of SBSE as a well-defined and worthwhile activity within the rich and diverse tapestry of Software Engineering is reflected by the increasing number of survey papers on SBSE [ABHPW10, ATF09, HMZ09, McM04, R ai09]. Further evidence for widespread interest and uptake, comes from the many special issues, workshops and conferences on the topic. However, this paper seeks to go a step further. It argues that Software Engineering is not merely an acceptable subject for the application of search based optimization, but that it is even better suited than all other areas of engineering activity, as a result of the very special properties of software as an engineering material.

## 2 Overview of SBSE

The existing case for SBSE in the literature rests upon the observation that

“Software engineers often face problems associated with the balancing of competing constraints, trade-offs between concerns and requirement imprecision. Perfect solutions are often either impossible or impractical and the nature of the problems often makes the definition of analytical algorithms problematic.” [HJ01]

The term SBSE was first used by Harman and Jones [HJ01] in 2001. The term ‘search’ is used to refer to the metaheuristic search-based optimization techniques. Search Based Software Engineering seeks a fundamental shift of emphasis from solution construction to solution description. Rather than devoting human effort to the task of finding solutions, the search for solutions is *automated* as a search, guided by a fitness function, defined by the engineer to capture *what* is required rather than *how* it is to be constructed. In many ways, this approach to Software Engineering echoes, at the macro level of Software Engineering artefacts, the declarative programming approach [DB77], which applies at the code level; both seek to move attention from the question of ‘how’ a solution is to be achieved to the question of ‘what’ properties are desirable.

Harman and Jones argued that SBSE could become a coherent field of activity that combines the expertise and skills of the Metaheuristic Search community with those of the Software Engineering community. Though there was previous work on the application of search based optimization to Software Engineering problems [CCHA94, JES98, TCM98, XES<sup>+</sup>92], the 2001 paper was the first to articulate SBSE as a field of study in its own right and to make a case for its wider study.

Since the 2001 paper, there has been an explosion of SBSE activity, with evidence for a rapid increase in publications on the topic [HMZ09]. For example, SBSE has been applied to testing [BSS02, Bot02, BLS05, GHHD05,

HHH<sup>+</sup>04, MHBT06, WBS01], bug fixing [AY08, WNGF09] design, [HHP02, MM06, SBBP05], requirements, [BRSW01, ZFH08], project management [AC07, ADH04, KSH02] and refactoring. [OÓ06, HT07]. There have been SBSE special issues in the journals Information and Software Technology (IST), Software Maintenance and Evolution (JSME) and Computers and Operations Research (COR) with forthcoming special issues in Empirical Software Engineering (EMSE), Software Practice and Experience (SPE), Information and Software Technology (IST) and IEEE Transactions on Software Engineering (TSE). There is also an established Symposium on Search Based Software Engineering (SSBSE), a workshop on Search Based Software Testing (SBST) and a dedicated track of the Genetic and Evolutionary Computation Conference (GECCO) on SBSE.

## 2.1 All You Need Is Love of *optimization*; You Already Have Representation and Fitness

Getting initial results from SBSE is relatively straightforward. This has made SBSE attractive to researchers and practitioners from the Software Engineering community. Becoming productive as a Search Based Software Engineer does not require a steep learning curve, nor years of apprenticeship in the techniques, foundations and nomenclature of Optimization Algorithms. It has been stated [Har07d, HJ01] that there are only two key ingredients required:

1. The choice of the representation of the problem.
2. The definition of the fitness function.

Of course, a Software Engineer is very likely to have, already at their disposal, a workable representation for their problem. Furthermore, Harman and Clark argue that

“Metrics are Fitness functions too” [HC04].

They argue that the extensive body of literature on metrics and software measurement can be mined for candidate fitness functions. This would allow Software Engineers to optimize according to software measurements, rather than merely to passively measure software artefacts. Though every metric may not be effective, because some may fail to measure what they claim to measure [She95], this need not be a problem. Indeed, one of the attractive aspects of metrics as fitness functions, is that such failings on the part of the metrics will become immediately evident through optimization. Harman and Clark show that there is a close connection between metrics as fitness functions and empirical assessment of the representation condition of software measurement.

## 2.2 Algorithms

The most widely used algorithms in SBSE work have, hitherto [HMZ09], been local search, simulated annealing genetic algorithms and genetic programming.

However, other authors have experimented with other search based optimizers such as parallel EAs [AC08], evolution strategies [AC05], Estimation of Distribution Algorithms (EDAs) [SL08], Scatter Search [BTDD07, AVCTV06, Sag07], Particle Swarm Optimization (PSO) [LI08, WWW07], Tabu Search [DTBD08] and Local search [KHC<sup>+</sup>05].

### 3 Why Software Engineering is the ‘Killer Application’ for Search Based Optimization

Previous work has considered the motivation for SBSE in terms of the advantages it offers to the Software Engineer. For instance it has been argued [HMZ09, Har07b] that SBSE is

1. **Scalable**, because of the ‘embarrassingly parallel’ [Fos95] nature of the underlying algorithms which can yield orders of magnitude scale up over sequential implementations [LB08].
2. **Generic**, due to the wide prevalence of suitable representations and fitness functions, right across the Software Engineering spectrum.
3. **Robust**, due to the ability of search based optimization to cope with noise, partial data and inaccurate fitness.
4. **Insight-rich**, as a result of the way in which the search process itself can shed light on the problems faced by decision makers.
5. **Realistic**, due to the way in which SBSE caters naturally for multiple competing and conflicting engineering objectives.

These five features of SBSE are important and have been described in more detail elsewhere [HMZ09, Har07b]. However, most are reasons for the use of search based optimization in general. They apply equally well to any class of optimization problems, both within and without the field of Software Engineering. This does not make them any less applicable to Software Engineering. However, it does raise the question as to whether there are any special software-centric reasons why SBSE should be considered to be an attractive, important and valuable field of study in its own right. That is, we ask:

Are there features of Software Engineering problems that make search based optimization particularly attractive?

Perhaps unsurprisingly, the author’s answer to this question is: ‘yes’. The rest of this paper seeks to explain why.

In more traditional engineering disciplines, such as mechanical, biomedical, chemical, electrical and electronic engineering, search based optimization has been applied for many years [BW96, CHS98, LT92, PCV95]. These applications denote a wide spectrum of engineering activity, from well-established traditional fields of engineering to more recent innovations. However, for each, it has been possible and desirable, to optimize using search based optimization. This is hardly surprising. After all, surely engineering is all about optimization.

When we speak of finding an engineering solution, do we not include balancing competing practical objectives in the best way possible? It should not be surprising, therefore, that optimization algorithms play a very important role.

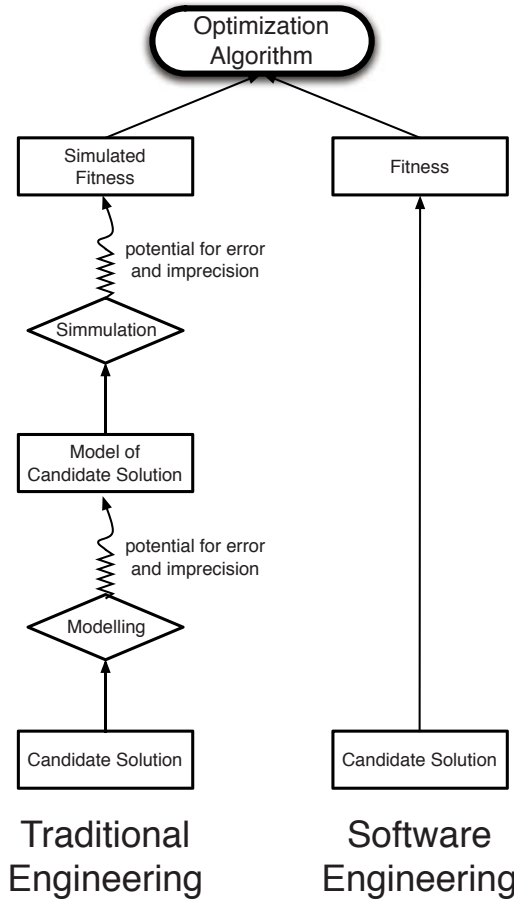
In all of these fields of engineering, the application of optimization techniques provides the engineer with a mechanism to consider many candidate solutions, searching for those that yield an acceptable balance of objectives. The advent of automatic high speed computation in the past sixty years has provided a huge stimulus to the optimization community; it has allowed this search to be automated. Guided by a fitness function, automated search is one of the most profitable and archetypal applications of computation. It allows a designer to focus on the desired properties of a design, without having to care about implementation details.

It is the advent of software and the platforms on which it executes that has facilitated enormous breakthroughs in optimization methods and techniques. However, it is only comparatively recently that Software Engineering has started to catch up with this trend within the wider engineering community. This seems curious, since search based optimization can be viewed as a software technology. Perhaps it reflects the comparatively recent realization that the activity of designing and building software-based systems is, indeed, an engineering activity and thus one for which an optimization-based world view is important.

When we speak of software we mean more than merely the code. We typically include requirements, designs, documentation and test cases. We also include the supporting logical infrastructure of configuration control, development environments, test harnesses, bug tracking, archives and other virtual information-based resources that form part of the overall system and its development history. The important unifying property of all of this information is that it is purely logical and without any physical manifestation. As every software engineer knows, software is different from every other engineering artefact; very different. One cannot see, hear, smell, touch nor taste it because it has no physical manifestation.

This apparently trite observation is *so* obvious that its importance can sometimes be overlooked, for it is precisely this *virtual* nature of software makes it even better suited to search based optimization than traditional engineering artefacts. The materials with which we perform the automated search are made of the same ‘virtual stuff’ as the artefacts we seek to optimize. This has profound implications for the conduct of search based optimization because it directly impacts the two key ingredients of representation and fitness (see Figure 1).

In traditional engineering optimization, the artefact to be optimized is often simulated. This is typically necessary precisely because the artefact to be optimized is a physical entity. For instance, if one wants to optimize an aircraft engine, one cannot search the space of real engines; building even a small subset of such candidate engine designs would be prohibitively expensive. Rather, one builds a *model* of the engine (in *software*), capturing, hopefully realistically and correctly, those aspects of performance that are of interest. Furthermore, in order to compute fitness, some form of simulation of the model is required. This



**Fig. 1.** Direct Application of Optimization is Possible with SBSE

allows us to explore the space of possible engine models, guided by a simulation of their likely real fitness.

Modeling and simulation create two layers of indirection and consequent potential for error. The model may not be entirely accurate. Indeed, if we are able to build a perfect model, then perhaps we would know so much about the engineering problem that we would be less likely to need to employ optimization. The fitness of each candidate model considered is calculated indirectly, in terms of the performance of the model with respect to some simulation of its real world behaviour. Once again, this introduces indirection and with it, the potential for error, imprecision and misunderstanding.

Contrast this traditional, physical engineering scenario with that of SBSE. For instance, consider the widely studied problem of finding test data. Suppose we wish to find test inputs that traverse a chosen branch of interest [ABHPW10, HMZ09, McM04]. For this problem there is no need for a model of the software

to be tested nor the test case to be applied. Rather than modeling the test case, the optimization is applied directly to a vector which *is* the input to the program under test. Furthermore, in order to compute fitness, one need not *simulate* the execution, one may simply execute directly.

Of course, some instrumentation is required to facilitate fitness assessment. This can create issues for measurement if, for example, non-functional properties are to be optimized [ATF09, HMZ09]. These bear a superficial similarity to those present with simulations. The instrumented program is not the real program; it could be thought of as a kind of model. However, the instrumented program is clearly much closer to the original program under test than a simulation of an engine is to a real physical engine.

Furthermore, many software testing objectives, such as structural test adequacy criteria [ABHPW10, HMZ09, McM04], are entirely unaffected by instrumentation and so there is no indirection at all. This observation applies in many aspects of software engineering. The problem of finding suitable sets of requirements operates on the requirements sets themselves. This is also true for optimization of regression test sets and for optimization of project plans and architectures.

Of course, there are some aspects of software systems which are modeled. Indeed, there is an increasing interest in model driven development. When SBSE is applied to these models, at the design level [Räi09], it may be the case that search based optimization for Software Engineering acquires a closer similarity to search based optimization for traditional engineering. Nevertheless, there will remain many applications for which SBSE is ideally suited to the problem because the engineering artefact is optimized directly (not in terms of a model) and the fitness is computed directly from the artefact itself (not from a simulation thereof).

## 4 Conclusions

Search Based Software Engineering (SBSE) is a newly emergent paradigm for both Software Engineering community and the Metaheuristic Search and optimization communities. SBSE has had notable successes and there is an increasingly widespread application of SBSE across the full spectrum of Software Engineering activities and problems. This paper is essentially a ‘position paper’ that argues that the unique ‘virtual’ property of software as an engineering material makes it ideally suited among engineering materials for search based optimization. Software Engineers can build candidate Software Engineering artefacts with comparative ease and little cost compared to traditional engineers, faced with physical artefact construction and consequent cost. In general, the Software Engineer can also measure fitness directly, not in terms of a (possibly imprecise or misrepresented) simulation of real world operation.

## 5 Author Biography

Mark Harman is professor of Software Engineering in the Department of Computer Science at King’s College London. He is widely known for work on source

code analysis and testing and he was instrumental in the founding of the field of Search Based Software Engineering, the topic of this keynote. He has given 14 keynote invited talks on SBSE and its applications in the past four years. Professor Harman is the author of over 150 refereed publications, on the editorial board of 7 international journals and has served on 90 programme committees. He is director of the CREST centre at King's College London.

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