A Proposed Heuristic for a Computer Chess Program

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Abstract

How might we create an evaluation function for a computer chess program that plays a stronger positional game of chess? A new heuristic for estimating the positional pressure produced by chess pieces is proposed. We construct an evaluation from a Systems perspective, using a dynamic model of the interaction of the pieces. The identification and management of stressors and the construction of resilient positions allow effective cut-offs for less-promising game continuations due to the perceived presence of adaptive capacity. We calculate and maintain a database of potential mobility for each chess piece 3 moves into the future, for each position we evaluate in our search tree. We determine the likely restrictions placed on the future mobility of the pieces based on the attack paths of the lower-valued enemy pieces. Initial results are presented.

keywords: complexity, chess, game theory, constraints, heuristics, planning, measurement, diagnostic test, resilience

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1 Overview

The complexity present in the game of chess often hinders planning efforts and makes simple questions like "what's going on?" and "which side has the better position?" difficult to answer.

Indeterminate and unexpected events in the near future might make revisions necessary for these plans, often after only a few moves have been played.

We theorize that dynamic planning models based on perceptions of constraints, the management of stress, the readiness of resources to support strategy, resiliency, sustainable development, and sensitivity to both incremental progress towards goals and the emergence of new opportunities can be used with greater success. We seek positions which can serve as a platform for future success, in a future that is often uncertain.

A proposed heuristic for a machine playing the game of chess, taking advantage of concepts from multiple disciplines, can be used to better estimate the potential of resources to support strategy and to offer better insight for determining whether progress is being made towards remote goals. In a future that is uncertain, there is a benefit to develop a strategic position full of resilience, flexibility, and structures with the potential for seizing new opportunities as they emerge.

As we evaluate each game position, we now consider the potential to exploit and respond to new opportunities as time passes and new situations emerge from beyond our initial planning horizon. Our flexibility ideally allows a smooth and resilient response to concurrent events as they unfold. We theorize that our focus on the constraints, as well as the development of a resilient position, is a more useful level of abstraction for our game-playing machine.

We examine concepts and values useful for playing a positional game of chess, we develop a perception useful for measuring incremental progress towards goals, and then look at positions in chess games where the heuristic offers insight not otherwise obtainable. We conclude that our evaluation heuristic offers promise for a machine playing a game of chess, although our limited evidence (at present) consists of diagrams showing the strategic (dynamic) potential of the game pieces.

We see the chess position as a complex adaptive system, full of opportunities of emergence from interacting pieces. Our aim in this paper is to reengineer the work performed by our machine, mindful of the values commonly adopted by experts and the principles of Systems thinking, so that it might be done in a far superior way [hammer95].

2 Introduction

This paper is concerned with heuristic algorithms. According to [koen03] a heuristic is anything that provides a plausible aid or direction in the solution of a problem but is in the final analysis unjustified, incapable of justification, and potentially fallible. Heuristics help solve unsolvable problems or reduce the time needed to find a satisfactory solution.

A new heuristic is proposed which offers better insight on the positional placement of the pieces to a chess-playing computer program. The heuristic will have usefulness in the evaluation function of a computer program, or as part of a teaching tool which explains to a human user the reasons that one side or the other has an advantage in a chess game.

The heuristic involves constructing a table of the future mobility for each piece, taking into account the other pieces on the board, as well as the likely constraints that these other pieces place on this future movement. The heuristic concept is described, and then examples are presented from a software application constructed to demonstrate this concept.

Computer chess programs have historically been weak in understanding concepts relating to positional issues. The proposed heuristic offers a method to potentially play a stronger positional game of chess.

3 Principles of Positional Chess

Understanding the principles of positional chess is a necessary starting point before designing concepts useful for a machine implementation. We select the relevant concepts of positional chess which have been addressed by multiple authors.

[stean02] declares that the most important single feature of a chess position is the activity of the pieces and that the primary constraint on a piece's activity is the pawn structure. [znoskoborovsky80] generalizes this principle by declaring that if a piece attacks another, it is not the weaker but the stronger one which has to give way. [reshevsky02] notes that a *good* or *bad* bishop depends on placement of the pawns. Pieces should be "working" and engaged, delivering the full force of their potential and avoiding influences which constrain. [levy76] discusses a game where a computer program accepts a position with an extra piece out of play, making a win difficult, if at all possible. Our evaluation should therefore consider the degree to which a piece is in play or is capable of forcefully contributing to the game.

Stean defines a weak pawn as one which cannot be protected by another pawn, therefore requiring support from its own pieces. This is the *ability* to be protected by another pawn, not necessarily the present existence of such protection. Stean declares that the pawn structure has a certain capacity for efficiently accommodating pieces and that exceeding that capacity hurts their ability to work together.

[aagaard03] declares that all positional chess is related to the existence of weakness in either player's position. This weakness becomes real when it is possible for the weakness to be attacked. The pieces on the board and their constraining interactions define how attackable these weaknesses are.

[emms01] declares that is an advantage if a piece is performing several important functions at once, while a disadvantage if a piece is not participating effectively in the game. Emms teaches that doubled pawns can be weak if they are attackable or if they otherwise reduce the mobility of the pawns. Doubled pawns can control vital squares, which might also mean denying mobility to enemy pieces. Isolated pawns require the presence of pieces to defend them if attacked.

[dvoretsky96] argues that creating multiple threats is a good starting point for forming a plan. Improving the performance of the weakest piece is proposed as a good way to improve your position as a whole.

[mcdonald06] gives an example of *good* doubled pawns which operate to restrict the mobility of the opponent's pieces and are not easily attackable. His view is that every position needs to be evaluated according to the unique features present.

[capablanca02] and [znoskoborovsky80] speak of how the force of the chess pieces acts in space, over the chessboard, and through time, in sequential moves. Critical is the concept of *position*, which is valued by greater or lesser mobility plus the pressure exerted against points on the board or against opponent's pieces. Preeminence, according to Capablanca, should be given to the element of position. We are also instructed that the underlying principle of the middle game is co-ordinating the action of our pieces.

[heisman99] discusses the important elements of positional evaluation, including *global mobility* of the pieces and *flexibility*.

[albus01] has written that the key to building practical intelligent systems lies in our ability to focus attention on what is important and to ignore what is not. [kaplan78] says that it is important to focus attention on the few moves that are relevant and to spend little time on the rest.

The positional style is distinguished by positional goals and an evaluation which rewards pieces for their future potential to accomplish objectives. [ulea02] quotes Katsenelinboigen as saying that the goal of the positional style of chess is the creation of a position which allows for development in the future. By selecting appropriate placement of pieces, combinations ideally will emerge. [katsenelinboigen92] further describes the organizational strategy of creating flexible structures and the need to create potential in adaptive systems that face an unpredictable environment.

[botvinnik84] and [botvinnik70] attempt in general terms to describe a vision for implementing long range planning, noting that attacking the paths that pieces take towards objectives is a viable positional strategy. Positional play aims at changing or constraining the attack paths that pieces take when moving towards objectives - in effect, creating or mitigating stress in the position.

[hubbard07] identifies procedures which can be helpful when attempting to measure intangible values, such as the positional pressure produced by chess pieces. [spitzer07] declares that what gets measured get managed, that everything that should be measured, can be measured, and that we should measure what is most important.

4 Systems Engineering

A *system* [kossiakoff03] is a set of interrelated components working together toward a common objective. A *complex engineered system* is composed of a large number of intricately interrelated diverse elements. von Bertalanffy is of the opinion [vonbertalanffy68] that the concept of a system is not limited to material entities but can be applied to any whole consisting of interacting components. This description could also apply to the situation faced by an agent playing a game, where the pieces represent the interrelated diverse elements. von Bertalanffy further identifies *dynamic interaction* as the central problem in all fields of reality (which would include playing a game), identifying *system elements in mutual interaction* as the very core issue. Additionally, we are told to suspect systems or certain systems conditions at work whenever we come across something that appears vitalistic or human-like in attribution. We therefore see an opportunity to apply principles of System Theory, and in particular, Systems Engineering, to game theory.

How would we begin? We now apply basic principles of Systems Engineering from [kossiakoff03]:

A *needs analysis phase* defines the need for a new system. We ask "Is there a valid need for a new system?" and "Is there a practical approach to satisfying such a need?" Critically, can we modify existing designs, and is available technology mature enough to support the desired capability? The valid need would be to play a stronger positional game of chess, and existing technology has struggled with the concept of positional chess, as reflected in recent correspondence games which use Shannon-based programs. It would seem that we need a different approach, which might be as simple as attempting to emulate the style of play performed by strong human players.

The *concept exploration phase* examines potential system concepts in answering the questions: "What performance is required of the new system to meet the perceived need?" and "Is there at least one feasible approach to achieving such performance at an affordable cost?" We would answer the first question as simply that our software function as an adequate analysis tool, capable of selecting high-quality positional moves (with quality of move proportional to the analysis time spent) when left "on" for indefinite periods of time. As far as the second question, we might speculate that a new approach is needed, which feasibly we could model after humans playing the game.

The *concept definition phase* selects the preferred concept. It answers the question: "What are the key characteristics of a system concept that would achieve the most beneficial balance between capability, operational life, and cost?" To answer this question a number of alternative concepts might be considered and their relative performance, operational utility, development risk, and cost might be compared. The first concept we might consider would be the Shannon approach, which has been the backbone of most software computer chess programs. We present in this paper, defined in another section, another approach. We therefore decide to explore the concept definition phase in more detail, as we look for key system characteristics which conceptually could serve as the base of such a new system.

5 Systems Thinking

Systems thinking is a discipline for observing wholes [senge06]. It is a framework for observing interrelationships rather than things, for observing the effects of change rather than static snapshots. The heart of Systems thinking, which is different from analytical thinking, is the attempt to simplify complexity [gharajedaghi06]. We see an opportunity to apply principles of Systems thinking to game theory. [gharajedaghi06] discusses how independent variables are the essence of analytical thinking. We might find, on closer inspection, that our independent variables are not truly independent - that the whole is more than a simple sum of the parts. Emergent properties of a system are a product of interactions and cannot

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[gharajedaghi06] be analyzed or manipulated by analytical tools, and do not have causal explanations. We must instead attempt to understand the processes that produce them by managing the critical interactions. One might think of emergent properties as being in the process of unfolding. What makes it possible to turn the systems approach into a scientific approach is our belief that there is such a thing as approximate knowledge [capra88].

[gharajedaghi06] informs us that understanding consequences of actions (both short- and long-term, in their entirety), requires building a *dynamic model* to simulate the multiple-loop, nonlinear nature of the system. Our model should aim to capture the important delays and relevant interactions among the major variables, but need not be complicated.

We therefore attempt to approach the construction of an evaluation function from a Systems perspective. We will look at the interactions of the pieces and their ability to create and mitigate stress. We adopt constraints, vulnerability, dynamic modeling, and resiliency as higher level concepts which will help cut through the complexity and steer search efforts along the lines of the most promising moves. The technique of *modeling* [kossiakoff03] is one of the basic tools of systems engineering, especially in situations where complexity and emergence obscure the basic facts in a situation.

From [anderson97], we apply Systems thinking to look at the web of interconnected, circular relationships present in a chess position, confident that this is the proper tool for doing so. Our reason for believing this is that everything in a chess position is [anderson97] dynamic, complex, and interdependent. Things are changing all the time, analysis is messy, and the interactions of the pieces are all interconnected.

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As we attempt to construct resilient game positions, we follow [tierney07] and identify 4 system level components of resiliency: Robustness - the ability of our game-playing agent to withstand our opponent's forces without degradation or loss of performance; Redundancy - the extent to which pieces, structures or moves are substitutable, that is, capable of sustaining operations, if degradation or a surprise move occurs; Resourcefulness - the ability of our agent to diagnose and prioritize candidate moves and to initiate solutions by identifying and mobilizing appropriate amounts of search time and game resources; and Rapidity - the capacity to restore or sustain functionality in a timely way, containing losses by graceful failure and avoiding other disruptions.

6 Goldratt's Theory of Constraints and Thinking Process

[goldratt04] has developed a *Theory of Constraints* which postulates that organizations and complex systems are hindered from reaching their goals by the *constraints* placed on that system. Identifying those constraints and removing them can speed progress towards these goals. [scheinkopf99] describes how Golratt's institute began to modify the original concepts to serve the needs of clients who wanted more generalized procedures to solve a wider variety of problems outside of a factory production environment.

Goldratt's ideas, while seemingly original, can be properly classified as a Systems thinking methodolgy which emphasizes raw human thinking over the construction and implementation of computer models. Each approach is useful. Also emphasized is a vocabulary and terminology which allows groups to construct and discuss analytical diagrams of feedback loops and identify root causes.

[dettmer07] explores Goldratt's *Thinking Process* and identifies procedures to logically identify and eliminate undesirable effects from systems and organizations.

[dechter03] explains that a model of reality based on constraints helps us to achieve an effective focus for search efforts, and is similar to the heuristic process that humans use to search for effective solutions in complex situations. Removing the constraints partially solves the problem, and measured progress towards removing these constraints can steer and prune our search efforts when identifying positions and lines of analysis which are promising.

[hollnagel06] speaks of identifying and monitoring the "barriers" which keep the system response within safe margins. Also, the use of "audit tools" is envisioned as a method to measure the effectiveness of the containment.

7 Soft Systems Methodology

[checkland06] presents a modified Systems methodology where complexity and confusion are tackled through organized exploration and learning. We envision the continuous change present in the game of chess as a complex state that needs to be (at least partially) understood in order to make exploration efforts (of an exponentially growing search tree) more efficient.

We conceptualize a learning agent which gathers relevant information as it seeks to determine the cumulative stress present in the position, in order to determine the paths of exploration - the ones of promise and the ones of risk mitigation. Our Systems model (making up our evaluation function) will ideally suggest to us what moves are promising or worth our time exploring, as well as to recommend which paths can, justifiably, wait until later. The heuristics which make up this learning and decision making process will be discussed in a later section. Critical to these heuristics is the concept that all dynamic behavior emerges from a combination of reinforcing and balancing feedback loops [anderson97].

what we really need is an insightful and informed direction for exploration and a notion for how pressing this direction becomes strategically.

Curiously, our evaluation function will become a methodolgy rather than a formula. We share Botvinnik's puzzlement with an evaluation "number" [botvinnik70] when what we really need is an insightful and informed direction for exploration and a notion for how pressing this direction becomes strategically.

The insight we obtain by this method is used as a *spring for action* [checkland06], as our software agent decides what to do next, after completing the current evaluation. Our "evaluation" ideally produces candidate directions for exploration, as part of a carefully constructed strategic plan, and indicates which paths are critical and which can wait until later. For Checkland, our model is an *intellectual device* we use to richly explore the future, using stress transformation as our chosen strategy, or worldview. Simply put, our model tells us which paths to explore.

Our estimate of the winning chances of a candidate position critically depends on the identification and exploration of the critical candidate sequences of moves, and the correct classification of the worthiness (for timely exploration) of such candidate positions. A heuristic estimate of the cumulative stress present in the position, at the end of our principal variation, can be correlated, if desired, with winning chances. However, our operational use of this value is for (cybernetically) steering search efforts.

8 Measurement

What gets measured gets managed. [spitzer07] speaks about the critical need to develop metrics which are predictive and which measure strategic potential. We seek to measure how "ready" our pieces are (and the structures they form) for supporting strategy [kaplan04], especially when the future positions we face are not entirely determinable. An asset (such as a game piece) that cannot support strategy has limited value. Part of our evaluation of the promise of a position should ideally include the readiness of the pieces and structures to support future developments. We embrace the principle that what you look for is what you find.

For [zeller80], measurement clarifies our theoretical thinking and links the conceptual with the observable. For measurement to be effective, we must first construct a valid sensor. In our attempts at measurement, we seek empirical indicators which are valid, operational indicators of our theoretical concepts. We desire to construct a diagnostic indicator which gives, as a result, a useful predictive measure of future promise and a direction for future exploration.

Although it would seem that a perception based on simplicity would yield the best all-around results, [blalock82] points out the difficulties trying to simultaneously achieve simplicity, generality, and precision in our measurement. If we have to give up one of these three, it is Blalock's opinion that *parsimony*, or the scientific idea that the simplest explanation of a phenomenon is the best one, would have to be sacrificed in order to achieve the other two. Therefore, our attempts to describe a complex evaluation function are grounded in the two-fold goals of generality (it must be applied to all positions we encounter) and precision (otherwise, search efforts are wasted on less promising lines).

The alternative view is presented by [gunderson10], who declares that his experience has suggested to be as ruthlessly parsimonious and economical as possible *while still retaining responsiveness to the management objectives and actions appropriate for the problem*. Additionally, we are advised that the variables selected for system description must be *the minimum that will capture the system's essential qualitative behavior in time and space*. We are further cautioned that the initial steps of bounding the problem determine whether the abstract model will usefully represent that portion of reality relevant to policy design. We must therefore aim to simplify, but not so much as to impact the usefulness of the tool for predicting promising paths of exploration.

9 Vulnerability

Critical to the success of a computer chess program that attempts to play in the positional style is the concept of vulnerability. The pieces and structures that are or have the potential to become vulnerable will become a focus of our search and exploration efforts and will serve as targets for our long-range planning.

We follow [mccarthy01] and conceptualize vulnerability as a function of exposure, sensitivity, and adaptive capacity. Consequently, the sensor we develop should attempt to measure exposure to threats, the sensitivity to the effects of stimuli, and the ability to adapt and cope with the consequences of change. We envision a sensor that produces a forecast of potential vulnerability as an output. This forecast can guide exploration efforts by identifying targets for the useful application of stress and serve as one indicator of a promising position.

Additionally, we predict that any machine-based attempt to zero-in on vulnerability that does not address this conceptual base runs the risk of missing opportunities in exploring the exponentially growing tree of possibilities that exist for each game position. A missed opportunity might equally prevent us from increasing positional pressure on our opponent, or instead, might dissipate the pressure that we have carefully accumulated over time. Our evaluation of the winning chances present in the position might not be as accurate as it could be unless we explore the promising positions and consider the vulnerabilities that are present.

We conceptualize that the reduction of vulnerability and the pursuit of sustainable development are interrelated aims [smith03].

10 Resilience

Vulnerability is the condition that makes adaptation and resilience necessary as a mitigation [worldwatch09]. The scientific study of resilience began in the 1970s when Norman Garmezy studied well-adapted children who had overcome the stress of poverty [lukey08]. Resilience is also an important research area in military science [friedl07] and in the study of ecosystems [folke02]. We find this concept useful in game theory.

In our view, adapted from [luthar03], resilience refers to an ongoing, dynamic developmental process of strategically positioning resources that enables the player in a game to negotiate current issues adaptively. It also provides a foundation for dealing with subsequent challenges, as well as recovering from reversals of fortune.

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We desire a generic, continuous ability (both during crisis and non-crisis game situations) to cope with the uncertain positions that arrive from beyond our planning horizon. Ideally, we seek to create a useful positional pressure to force these arriving positions to be in our favor, or minimally, to put a "cage" of constraints around the enemy pieces. Flexibility, adaptive capacity, and effective engagement of available resources will be our weapons against the dynamic changes which will unfold in our game [hollnagel08].

Ideally, we will look for and manage the heuristic early warning signs of a position approaching a "tipping point", where a distinct, clear advantage for one side emerges from an unclear array of concurrent piece interactions. We agree with [walsh06] that resilience cannot be captured as a snapshot at a moment in time, but rather is the result of an interactive process that unfolds over time.

The failure to include resilience measurements like this in planning efforts might cause a house-of-cards effect, as the weakest link in our plan might collapse, due to effects we cannot initially perceive. This might create a situation from which we cannot recover, or from which we cannot continue to mount increasing positional pressure on our opponent.

A central concept is the construction of a *resilient position*, one that ideally 1. possesses a capacity to bounce back from disruption in the event of an unforeseen move by our opponent, 2. produces advantageous moves in light of small mistakes by our opponent, or 3. permits us to postpone our search efforts at early points for less promising positions, with greater confidence that we have sufficient resources to handle future unforeseen developments if the actual game play proceeds down that route. In simplest form, we might just measure the ability to self-organize.

When change occurs, the components that make up resilience provide the necessary capacity to (minimally) counter and (ideally) seize new opportunities that emerge [folke02]. Resilience is (minimally) insurance against the collapse of a position and (ideally) an investment that pays dividends in the form of better positions in the future. With no pun intended, we see the struggle to control the unknown, emerging future positions as a "Red Queen's Race", where in tough-fought games against a talented opponent, it might take all the effort possible to maintain equal chances. Extraordinary efforts involving hundreds of hours of analysis *per move* (such as in correspondence games) might be required to maneuver to an advantage [jerz07].

For [reivich02], resilience is the basic strength. [hollnagel06] suggests that "incidents", which for us might be the construction of short sequences of just the top few promising moves (diagnostic probing), might reveal insight to boundary conditions in which resilience is either causing the system to stretch to adapt, or buckle and fail. Emergency response teams use practice incidents to measure resilience as unforeseen events emerge during operations. Fire drills, random audits and security searches, even surprise tests are diagnostic tools used to detect and correct situations lacking in resilient capabilities.

We acknowledge the reality that our ability to handle an unexpected move or critical situation in a game depends on the structures already in place [weick07]. We desire [weick07] to pay close attention to weak signals of failure that are diagnostic indicators of potential problems in the system. We also perform diagnostic probing to uncover and steer game play towards positions where there are multiple good moves - an additional sign of resilience.

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We speculate that the ability to construct a resilient position and the ability to perceive stress in a position are two primary conceptual differences between a game-playing man and machine. We believe that these abilities can be emulated through the use of custom diagnostic tests.

Humans construct resilient positions (in strategic situations) almost by instinct and often without conscious thought [fritz03], in diverse situations such as driving automobiles, playing sports games, conducting warfare, social interaction, and managing resources in business or work situations. Humans have such refined abilities [laszlo96] to make predictions, interpret clues and manipulate their environment, that using them is frequently effortless, especially if performed daily or over extended periods of time. [aldwin07] points out that humans appear to be hard-wired physiologically to respond to their perceptions of stress - so much so that effective responses can be generated continuously with little conscious thought. We therefore see the machine-based perception of stress as critical to successful performance in a game.

Additionally, much has been written [fagre09] [folke02] concerning ecosystems, resilience, and adaptive management that has direct application to game theory.

Conceptually, we desire the equivalent of a "mindset" that can successfully cope with problems as they arise, as we attempt to 1. examine the promising positions, 2. evaluate the corresponding winning potential and 3. steer our search efforts through an exponentially growing "tree" of strategically important move sequences. This process is aided by the heuristic measurement of adaptive capacity, as the thousands of unexamined positions that lie just beyond the point of our search cut-offs must be resilient enough to counter whatever unknown events emerge. Before we cut-off our search efforts, we might choose to search the less resilient positions a little deeper as a mitigation of unforeseen events.

Rather than thinking about resilience as "bouncing back" from a shock or stress, it might be more useful to think about "bouncing forward" to a position where shocks and stresses have less effect on vulnerabilities [walsh06] [worldwatch09]. Integral to the definition of resilience are the interactions among risk and protective factors [verleye-prepub] at an agent and environmental level. Protective factors operate to protect assets, such as pieces in a game, at risk from the effects of the risk factors.

We agree and conceptualize that, while risk factors do not automatically lead to negative outcomes, their presence only exposes a game-playing agent to circumstances associated with a higher incidence of the outcome; protective or mitigating factors such as constraints can contribute to positive outcomes - perhaps regardless of the risk status.

We accept as an operational concept of resilience, the fourth proposal of Glantz and Sloboda [glantz99], which involves the adoption of a systems approach. We consider both positive and negative circumstances and both influencing and protecting characteristics and the ways in which they interact in the relevant situations. Additionally, this conceptualization considers the cumulation of factors and the influences of both nearby and distant forces. In addition, [elias06] discusses a model of resilience in which specific protective influences (which we see as constraints) moderate the effect of risk processes over time, in order to foster adaptive outcomes.

We propose [gunderson10] an approach based on resilience, which would emphasize the need to keep options open, the need to view events in a larger context, and the need to emphasize a capacity for having a large number of structural variations. From this we recognize our ignorance of, and the unexpectedness of future events. The resilience framework does not require a precise ability to predict the future, but only a capacity to devise systems that can absorb and accommodate future events in whatever unexpected form they may take. If we could cram MacGyver into our software, we would certainly do so.

11 Inventive Problem Solving

Our chess program attempts to be, like MacGyver, an inventive problem solver. We see effective problem solving as an adaptive process that unfolds based on the nature of the problem, rather than as a series of specific steps [albrecht07]. We agree with [browne02] that knowing the difference between what's important and what isn't is a basic starting point.

We attempt to navigate an exponentially growing search tree, selecting those paths for exploration that are promising, interesting, risk-mitigating, and resilient in the face of an unknown future. We are concerned at all times with the potential of a position to serve as an advancing platform for future incremental progress towards positional goals [fritz07]. We will accomplish this by knowing the outcomes we want and looking tirelessly for them. [savransky00] lists three major requirements for a problem-solving methodology, which we modify slightly for the purposes of a machine playing a game:

1. It should focus on the most appropriate and strongest solutions

2. It should produce, as an output, the most promising strategies

3. It should acquire and use important, well-organized, and necessary information at all steps of the process

[savransky00] additionally suggests that we should focus on gathering the important information, information which characterizes the problem and makes it clear, including contradictions. Any simplifications we perform should aim at reducing the problem to its essence and be directed towards our conceptual, strategic solution.

As an example, typical American news reports each day announce the results of the Dow Jones index of stocks. This index serves as a good indicator of overall market performance and can help answer the question "How did the markets do today?". We seek an equivalent summary numerical representation of reality [march94] which can serve as a guiding light and a measure of progress towards our distant positional goals. We are not restricted to the use of a single scoring metric, and can creatively combine multiple, critical metrics in creative ways, including the selection of the lowest score from several indicators to provide a search focus. We should first form a concept of what should be measured, then create a *sensor array* which allows us to measure and perform search efforts (in an exponentially growing tree of possible continuations) with reasonable efficiency.

12 The Strategic Plan

We see a strategic plan [bradford00] as a simple statement of the few things we really need to focus on to bring us success, as we define it. It will help us manage every detail of the game-playing process, but should not be excessively detailed. It will encapsulate our vision and will help us make decisions as we critically choose, or choose not, to explore future positions in our search tree. We see the formation and execution of the strategic plan as the most effective way to get nearer to the goal state, especially in a competitive environment where our opponent is also attempting to do the same.

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We see the role of the machine (in playing a game such as chess) as merely that of an executor of a strategic plan, where we have previously defined (through programmed software instructions) the specific answers to the questions "Where do we want to be?" "How will we know we have reached it?" "What is changing in the environment that we need to consider?" "Where are we right now?" and "How do we get from here to our desired place?" [haines98]. In our vision, the intelligence is located in the strategic answers to these questions and in the skill of the programmer in implementing them - we simply ask the machine to do what it is told.

If one game-playing computer program is better than another, as demonstrated in a tournament of many games played, we speculate that the reason is either a better strategic plan or a better software implementation of that plan. Therefore, improvements in computer chess programs ideally should focus on these two areas, including answers to the questions presented above. For Haines, all types of problems and situations (which include selecting a move in a game) can benefit from a strategic approach.

Before we develop our strategic plan, we ask ourselves and ponder 3 critical questions [jorgensen07]: 1. what are the underlying properties that can explain the responses we see on the game board to perturbations and interventions, 2. are we able to formulate at least building blocks of a management theory in the form of useful propositions about processes and properties, and 3. can we form a theory to understand the playing of chess that is sufficiently developed to be able to explain observations in a practical way for choosing a move? We do not see the need to construct mathematical proofs - the concept of a useful proposition allows us flexibility in choosing an approach and allows us to consider multiple options before settling on one with the most promise. We return to these critical questions whenever we seek direction or clarification in an approach, or consider starting over. We look to other disciplines and to other professionals who have sought answers to the same questions, which must be asked in a general way to any management problem.

Central to our strategic plan are the following concepts [jorgensen07]: system behavior frequently arises out of indirect interactions that are difficult to incorporate into connected models, that we may not know exactly what happens, but approximately what happens, and that we can use holistic metrics to measure the growth and development of a position in a game. We acknowledge that systems have a complex response to disturbances, and that constraints play a major role in interactions. As a strategy we seek a method to determine (and to resolve uncertainty concerning) 1. the promising candidate moves in a given position, and 2. the chances of sustainable development in a position, allowing us to postpone (if necessary) the exploration of future consequences.

In a building block for our strategic plan, we examine the position under evaluation for the presence of *stressors*

In a building block for our strategic plan, we examine the position under evaluation for the presence of *stressors* [glantz99] and determine their contribution to the *cumulative stress* in the position. A *stressor* is a real object on the game board, such as a piece, or an object or property that might become real in the future, such as a Queen from a promoted pawn, a stone in the game of Go, or a King in the game of draughts/checkers. Using our stressors, we seek to establish a *structural tension* [fritz89] that, if resolved, leads to positions that favor us.

The stress we seek to place on our opponent [glantz99] is the kind that interferes with or diminishes the development of our opponent's coping repertoire, search and planning abilities, expectations and potential resilience. This stress is ideally so effective that we create a platform from which we can apply even more stress. We force our opponent to divert additional resources to containing our threats, making fewer resources available for threats of his own.

We attempt to cope with the stressors of our opponent by weakening them or reducing their influence to a manageable level

We attempt to cope with the stressors of our opponent by weakening them or reducing their influence to a manageable level [snyder01] - there is no compelling need to make their effects go away completely. For [vonbertalanffy68], stress is a danger to be controlled and neutralized by adaptive mechanisms. We gather diagnostic information that is used to determine the readiness of the pieces to inflict stress on the opponent and lessen the stress imposed by the enemy pieces on our weak points. The creation of effective stress and the perceived mobilization of forces to mitigate it will become a central concept in our evaluation. Our evaluation looks not so much to goal seeking/optimizing a "score" as to sustaining relationships between/among the pieces and learning what happens as stress is moved from one area of the board to another.

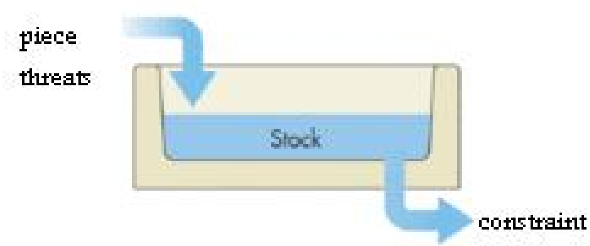

Figure 1: Simplified model (dynamic hypothesis) of positional pressure for each piece

Figure 1 shows a simplification of the proposed model of positional pressure for each piece, based on principles of system dynamics. The future mobility of each piece targets opponent pieces, the trajectories taken by these pieces, and certain other weaknesses such as weak pawns, the opponent's king, or undefended pieces. This threat is mitigated (but not reduced completely) by the *protective factor* of constraints imposed by the lower-valued enemy pieces. The residual "Stock" is the effective stress that can be felt by our opponent, and which we seek to increase. For [warren08], the management of critical resources is part of an emerging theory of performance: performance depends on resource contribution, resource contribution accumulates and depletes, and this depends on existing resource contribution levels.

Figure 2 shows the plan for managing the perceived stress by incentivizing a coping strategy, such as the placement of constraints, in order to control the effects of the overall cumulative stress. We seek to maintain a resilient position full of adaptive capacity.

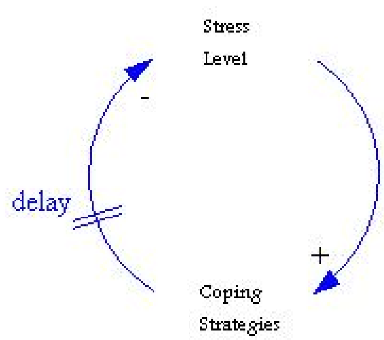

Figure 2: As perceived stress increases, we increase the incentive to cope with the stress

Things start to get complicated when we remove stress (and the associated constraints) from one area of the board and apply it to other areas. The short- and long-term effects of these stress-exchanging maneuvers are examined through prioritized search efforts, and in our opinion represent the essence of playing a game such as chess. This conceptual model will form the basis of the machine's perception. We rely on the simplifying principles of system dynamics to predict and anticipate the effects of such stress transformation.

From [friedl07] we define a *stressor* as any challenge to a player in a game that evokes a response. *Coping* is the set of responses that sustain performance in the presence of stressors. *Resilience* is the relative assessment of coping ability. We desire to create in our opponent's position a condition similar to *fatigue*, defined by Friedl (and modified for game theory) as the state of reduced performance capability due to the inability to continue to cope with stressors. We follow [fontana89] and define *stress* as a demand made upon the adaptive capacity of a player in a game by the other. We theorize a correlation between the state of stress-induced reduced performance capability and an "advantage", or favorable chances for the more capable player winning the game.

we are dealing with a process whose effects take time in revealing themselves

Strategically, we seek to identify the stress present in the position by 1. examining the demands of each stressor, 2. the capacity of each player to respond to those demands, and 3. the consequences of not responding to the demands.

we will predict the winning chances at some future point in time, after the present circumstances progress and the structures in place are allowed to unfold

We carefully define *weakness* so that the stress and tension we create is focused and effective. The information we gather from the interacting pieces should be precise enough to get results - it does not need to be perfectly accurate. Information is power [bradford00], especially in strategic planning. Along the way, we will need to make assumptions about whether or not the stress we are inflicting on our opponent is increasing or decreasing, and whether it is effective or not effective. We might explore promising paths in detail to confirm our assumptions, or we might just rely on our measurements of resilience.

Critical is our ability to focus our search efforts on lines that are promising, with regard to the oriented application of stress and the predicted effects on future lines of play. In our opinion [schumpeter08], we are dealing with a process whose effects take time in revealing themselves - we will predict the winning chances at some future point in time, after the present circumstances progress and the structures in place are allowed to unfold, including the newly emergent features which we are not currently able to perceive. We establish a portfolio of promising lines, and see where they go. We invest our time and processor resources in the *most* promising, but only after investigating the promising via a swarm of lower-risk experiments [hamel03]. We define a concept of stress which lets us focus our search efforts on anticipated promising lines. We rely on the promise of adaptive capacity present in resilient positions to sustain our efforts in lines where the perception of weaker cumulative stress, time constraints, and our model of purposeful activity do not permit us to explore.

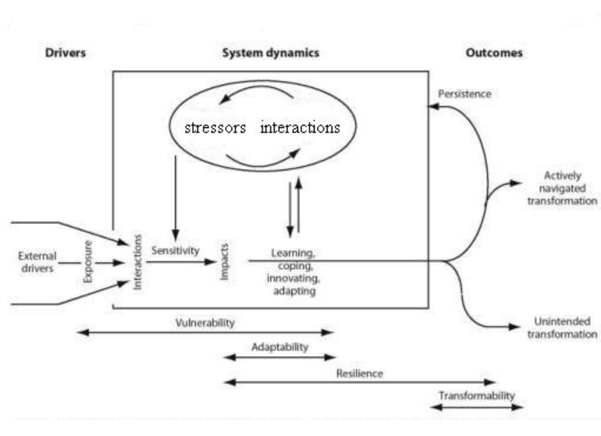

Figure 3: Conceptual Framework, from Chapin, 2009, p.21, (placeholder until new diagram is created)

We theorize that the dynamic forces of change during the playing of a game have an adaptation cost associated with them [kelly04] [zeidner96]. This might come from a shift in expectations, or from a required recovery from disruptions. We make "payments" for these adaptation costs from our "bank" of resilience. If we lose our positional resilience, we lose our flexible ability to adapt to the unknown requirements of change. Likewise, we can make "deposits" to our resilience account during quiet periods of maneuver, if we choose, and if we value resilience as an element of our evaluation function. [friedl07] refers to this concept as *pre-habilitation*. We seek to attack our opponent's capacity to respond and to strengthen our own, so that the dynamic forces of change that drive the game continuation will cause the unknown positions arriving from beyond our planning horizon to be in our favor.

We seek a resilient mindset. Specifically, we follow [coutu03] and aim for three fundamental characteristics: we identify and face the reality of the stresses and constraints present in the positions we evaluate, we identify and reward the values of positional chess, and we develop an ability to improvise solutions based on whatever resources are available to us. We seek to prepare for an unknown future that can be influenced by the strategic placement of resources in the present.

In the generalized exchange of pieces, squares, and opportunities encountered in game playing [botvinnik70], we seek to establish a pressure that has a realistic chance to resolve in our favor, as determined by heuristic probing and the examination of promising future game sequences. We desire to create and sustain a web of stress which threatens to become real and therefore has the property that [vonneumann53] has called "virtual" existence. Our opponent must "spend" or dedicate resources to contain or adapt to the threats. Even if a particular threat is contained, it nevertheless has participated in the dynamic shaping and influencing of the events that emerge and unfold in the game.

We will succeed at forming an effective strategic plan when we have identified our values, determined the key drivers to performance, developed a sensor which is effective at measuring them, and have focused on the lines of play that are promising. At all times we wish to maintain a resilient position, which increases our ability to effectively handle the unknown positions which lie beyond the horizon of our explorations.

We will use two key strategies [maddi05] to become and remain resilient: we will develop the vision to perceive changes in the promise of a position (as they emerge from our heuristic explorations), and we seek flexibility to act quickly, while remaining focused on our goals of establishing and maintaining a useful structural tension. We seek [kelly04] a balanced portfolio of resilience skills, where ideally we are focused, flexible, organized, and proactive in any given situation. We believe that resilient responses [kelly04] are the result of resilience characteristics operating as a system, as we evaluate and predict the emergent results of change.

Following [jackson03], *we avoid placing a complete reliance on specific predictions of the future*, concentrating on relationships, dynamism and unpredictability as much as we do on determinism. In our plan, we will adapt as necessary and seize new opportunities as they emerge from the "mess". We seek to focus on identifying and managing the structures that will drive the behavior of the game, and acknowledge the reality that large portions of the future possibilities will go unsearched and unexplored (until they emerge from beyond our planning horizon and into our perception). As we deepen our exploration and learning, we see new opportunities emerging as much for us as for our opponent, and requiring us to re-direct our search (and planning) efforts.

Where possible, we follow the advice of French military strategist Pierre-Joseph Bourcet [alexander02] and spread out attacking forces over multiple objectives, forcing an adversary to divide his strength and prevent concentration. Such divided forces - a "plan with branches", can be concentrated at will, especially if superior mobility is present, as recommended by French military strategist Guibert. As an end result of all this positional pressure and maneuver, we seek what Napoleon sought, that is [alexander02], the nature of strategy consists of always having (even with a weaker army) more forces at the point of attack or at the point where one is being attacked than the enemy. Such positions have the possibility of the win of material, and are then approached from a more tactical perspective - one that current heuristics handle well.

13 From Orientors to Indicators to Goals

We identify and adapt the approach of [bossel94] [bossel98] and [muller98] to conceptualize the 'health' and evaluation of a chess position, which in our vision shares much with that of an ecosystem. We seek indicators which realize Bossel's 6 basic high-level orienting properties of *existence and subsistence, effectiveness, freedom of action, security, adaptability, and coexistence.* We theorize with Bossel that these properties are each vital diagnostic indicators of successful system development, and we aim to steer our search efforts along paths which seek to improve the weakest of these properties. These indicators must give a fairly reliable and complete picture of what really matters [bossel98]. If a system is to be viable in the long run, a minimum satisfaction of each of these basic orientors must be assured [bossel94].

> We have found six basic system orientors (existence and subsistence, effectiveness, freedom of action, security, adaptability, coexistence) that apply to all autonomous self-organizing systems -Hartmut Bossel

We see a value in the two-phased approach of [bossel94]: first, a certain minimum qualification must be obtained separately for each of the basic orientors. A deficit in even one of the orientors potentially threatens our long-term survival from our current position. Our computer software will have to focus its attention on this deficit. Only if the required minimum satisfaction of all basic orientors is guaranteed is it permissible to try to raise system satisfaction by improving satisfaction of individual orientors further - if conditions, in particular our opponent, will allow this.

We see *goal functions* as operating to translate the fundamental system needs expressed in the basic orientors into specific objectives linking system response to properties observed on the chess board. We conceptualize that goal functions emerge as general properties in the coevolution of the chess position and dynamic, future development. They can be viewed as specific responses to the need to satisfy the basic orientors. For example, mobility is related to adaptability, constraints relate to coexistence, king safety is related to the orientors of security and existence, virtual existence and stress are related to effectiveness, material is related to existence, security and adaptability, etc. We can derive a new metric if we wish, but it needs to be related to one of the 6 orientors. We see orientors as a 'dimension of concern', and operating at a higher level of abstraction than a goal.

We can creatively come up with new indicators for our evaluation, but we see them fitting within the proposed framework of orientors and 'dimensions of concern' as outlined previously. We see the chess programs of the future as addressing this conceptual foundation, in creative ways and approaches that cannot yet be envisioned by today's developers. Our conceptualization of stress management and the construction of resilient positions as indicators are, ideally, part of an operational realization of the six orientors. If our concept fails as an orientor or focus of search efforts, then it needs to be modified or itself re-engineered. Perfectly usable indicators might overlap, or require too much processor time to implement. Perhaps what is required is the art of a talented programmer to select a set of indicators which also orient with effective insight.

> Our immediate goals, therefore, emerge from the weakest indicators (results) of the vital diagnostic tests, and operate to focus the search efforts along lines that allow sustainable development in the uncertain future.

What we are saying is simply that we must pay attention to each of these orientating qualities separately - we should not just roll them up into a grand, universal "number" and expect to effectively and efficiently drive our search efforts in that fashion. A weakness in one of the 6 orientors critically impacts sustainable development in the uncertain future and *cannot* be "made up for" with a higher score from the others. A simple mechanism for scoring, such as averaging the lower 2 indicators (of 6 total, one for each orientor), will make sure that the machine pays attention to (and focuses attention on) those orienting parameters that are in need of improvement. Our orienting indicators can all be based on a common foundation, such as cumulative stress, but with a weighting that aims to highlight the particular dimension of concern. What good is being a piece up if your King is in the center of the board, surrounded by enemy pieces? Better to see if we can return the King to a safe place, even at the price of material, so that we can continue the sustainable development of our position in the future. We therefore orient our future searching in ways to improve King safety. Our immediate goals, therefore, emerge from the weakest indicators (results) of the vital diagnostic tests, and operate to focus the search efforts along lines that allow sustainable development in the uncertain future.

14 Shannon's Evaluation Function

Shannon proposed [shannon50] a simple evaluation to be performed in relatively quiescent positions. While recent tournaments have shown that such evaluations (combined with *alpha-beta pruning* and the *null-move* heuristic) can be used to produce world-class chess programs, we seek an alternate approach with the capability of even better performance. Programs that use Shannon's evaluation often have trouble figuring out what to do when there is no direct sequence of moves leading to the placement of pieces on better squares (such as the center), or the acquisition of a "material" gain.

> Networks are comprised of a set of objects with direct transaction (couplings) between these objects... these transactions viewed in total link direct and indirect parts together in an interconnected web, giving rise to the network structure...

We see a general correlation between the placement of a piece on a "good square" and the ability of that piece to inflict stress on the opponent, and to mitigate the effects of stress caused by well-placed opponent's pieces. We even see that the concept of mobility has value in a general sense. However, we see problems with this technique being used to build positional pressure, such as the kind needed to play an effective game of correspondence chess. The long and deep analysis produced by the machine is often focused in the wrong areas, as determined by the actual course of the game.

> ...The connectivity of nature has important impacts on both the objects within the network and our attempts to understand it. If we ignore the web and look at individual unconnected organisms... we miss the system-level effects. -Jorgensen, Fath, et al., A New Ecology, p.79

The stress produced by the Shannon method is not of the type that reduces the coping capacity of the opponent, or increases our own resilience, in certain game situations where positional play is required. For example, in positions that are empty of tactical opportunities, the machine can be effectively challenged by opponents who know how to play a good positional game of chess [nickel05]. The terms of the Shannon evaluation function do not seem suitable metrics for guiding search and planning efforts, in these cases.

[fontana89] advises us to ask: what are the stressors, what needs to be done about them, and what is stopping us from doing it? There is little to be gained from generalizing, if our goal is to identify the stressors, accurately assess the levels of stress present, and mobilize according to the results.

15 The Positional Evaluation Function

We propose that an approach which attempts to increase the *oriented positional pressure* or cumulative stress on the opponent, even if unresolved at the terminal positions in our search tree, is a viable strategy and has the potential to play a world-class game of chess. Our strategic intent is to form targeted positional pressure (aimed at weakpoints defined by chess theory and at constraining the movement of the enemy pieces) that will resolve *at some future point in time* into better positions, as events unfold and gameplay proceeds. At minimum, this pressure will allow for sustainable development as one component of a resilient position. We will not judge pieces by the ”squares” they occupy, but instead, by our heuristic estimate of the level of focused stress they can contribute (or mitigate) in the game.

We construct an evaluation function with the goal of making our machine more knowledgeable with regard to the positional concepts discussed earlier. In designing our evaluation function, we heed the advice of [dombroski00] that our evaluation function is our test of effects and consequences and is our guiding light in our search for the consequences of our choices.

Our evaluation centers on a heuristic appraisal of the stress we inflict on the opponent’s position, and our mitigation of the stress created by the opponent. We aim to reduce our opponent’s coping ability through careful targeting of stress. The dynamic forces of change, acting over time and in a future we often cannot initially see, transform the reduced coping ability of our opponent, our carefully targeted stress, and our resilient position full of adaptive capacity, to future positions of advantage for us.

Perhaps this concept is what inspired Bobby Allison to race most of the 1982 Daytona 500 without a back bumper - it fell off after contacting another car early in the event [nascar09]. Some drivers accused Allison’s crew chief of rigging the bumper to intentionally fall off on impact. Allison’s car without the bumper had improved aerodynamics, and the forces of dynamic change operating over the 500 mile race supplied the driver with an advantage he used to win. Other examples (the winged keel of the Australia II yacht and the new loop-keel design, hinged ice skates and performance enhancing swimsuits come to mind) show how small changes, combined with other critical abilities and *interacting with a dynamic environment over time*, can create a performance advantage. We seek, in similar fashion, to favor certain interacting arrangements of pieces, such that the dynamic forces of change (operating during the playing of a game) cause favorable positions to emerge over time, from beyond our initial planning horizon. We seek to re-conceptualize the ”horizon effect” to our advantage. We cannot arrange for a bumper to fall off during a chess game, but we can do the equivalent - we can actively manage the dynamics of change to improve the chances for persistence or transformation [chapin09]. This would include the general approaches of reducing vulnerability, enhancing adaptive capacity, increasing resilience, and enhancing transformability [chapin09]. We manage the *exposure* to stress, in addition to the *sensitivity* to stress [chapin09].

So we need something like a map of the future. A map does not tell us where we will be going, or where we should be going - it merely informs us about the possibilities we have... We therefore need a description of the possibilities ahead of us...

We adopt the vision of [katsenelinboigen92], that we define a "potential" which measures a structure aimed at forcing events in our favor. Ideally, one which also absorbs or reduces the effects of unexpected events.

...Such a map would not have to give us very detailed information... But it should give us a useful image of what may be ahead, and allow us to compare the relative merits of different routes... before we embark on our journey. - Hartmut Bossel

We follow the suggestion in [pearl84] to use as a strategy an evaluation based on a *relaxed constraint* model, one that ideally provides (like human intuition), a stream of tentative, informative advice for managing the steps that make up a problem-solving process, and use the insight from [fritz89] and [sterman00] that structure influences behavior.

In order to more accurately estimate the distant positional pressure produced by the chess pieces, as well as to predict the future capability of the pieces in a basic form of planning [lakein74] [shoemaker07] we create the software equivalent of a *diagnostic probe* which performs a heuristic estimate of the ability of each piece to cause and mitigate stress. The objectives we select for this stress will be attacking enemy pieces, constraining enemy pieces, and supporting friendly pieces (especially those pieces that are weak). To support this strategy, we calculate and maintain this database of potential mobility for each chess piece 3 moves into the future, for each position we evaluate.

Sustainability... means, as said before, that only the riverbed, not the exact location of the river on it, can and should be specified - Hartmut Bossel

We update this piece mobility database dynamically as we evaluate each new leaf position in our search tree. This database helps us determine the pieces that can be attacked or supported in the future (such as 2 moves away from defending a piece or 3 moves away from attacking a square next to the enemy king), as well as *constrained* from accomplishing this same activity. Note that the piece mobility we calculate is the means through which we determine the pressure the piece can exert on a distant objective. We can therefore see how mobility (as a general concept) can become a vital holistic indicator of system health and one predictor of sustainable development.

We reduce our bonus for each move that it takes the piece to accomplish the desired objective. We then consider *restrictions* which are *likely* to constrain the piece as it attempts to make moves on the board.

For example, let's consider the pieces in the starting position (Figure 4).

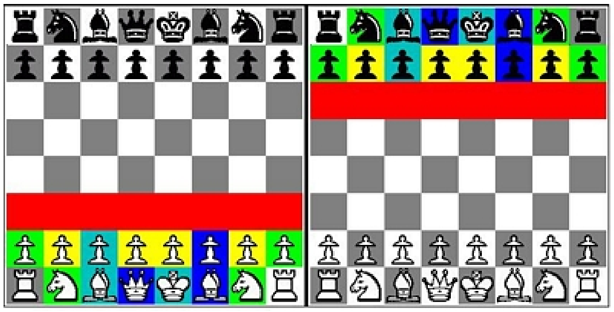

Figure 4: White and Black *constraint map*, pieces at the starting position Legend: Red: pawn constraints, Yellow: Minor piece constraints, Green: rook constraints, Blue-green: Queen constraints, Blue: King constraints

What squares can our knight on g1 influence in 3 moves, and which squares from this set are likely off-limits due to potential constraints from the enemy pieces?

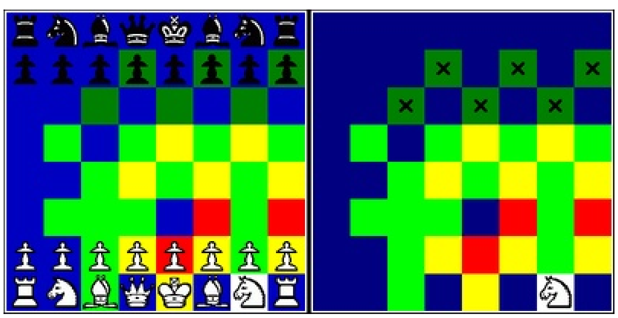

Figure 5: Influence Diagram and Simulation Diagram, Ng1 at starting position *Legend:* Red - 1 move influence, Yellow - 2 move influence, Green - 3 move influence, Dark Red - 1 move influence possibly constrained by opponent piece, Dark Yellow - 2 move influence possibly constrained by opponent piece, Dark Green - 3 move influence possibly constrained by opponent piece, Blue - no influence possible within 3 moves, X - presence of potential constraint

We now construct the *influence diagram* [shoemaker07] and the *simulation diagram* [bossel94] (Figure 5), which are interpreted in the following way. If a piece is on our influence diagram for the knight, then it is possible to attack it or defend it in 3 moves (this includes waiting moves or moves which move a piece out of the way). We label this kind of map an *influence diagram* because it shows the squares that the piece can influence in 3 moves, provided that it is unconstrained in movement by the enemy.

Keep in mind that we need to take into account the location of the other pieces on the chessboard when we generate these diagrams for each piece. If we trace mobility through a friendly piece, we must consider whether or not we can move this piece out of the way before we can continue to trace mobility in that particular direction. If we trace mobility through an enemy piece, we must first be able to spend 1 move capturing that piece.

Comparing this 3-move map with a diagram of the starting position, we can determine that the white knight on g1 can potentially attack 3 enemy pieces in 3 moves (black pawns on d7, f7 and h7). We can defend 8 of our own pieces in 3 moves (the knight cannot defend itself).

We decide to reward pieces for their potential ability to accomplish certain types of worthwhile positional objectives: attacking or constraining enemy pieces, defending friendly pieces, attacking squares near our opponents king (especially involving collaboration), minimizing our opponent's ability to attack squares near our own king, attacking pieces that are not defended or pawns that cannot be defended by neighboring pawns, restricting the mobility of enemy pieces (specifically, their ability to accomplish objectives), etc. In this way, we are getting real about what the piece can do. The bonus we give the piece is 1. a more precise estimate of the piece's ability to become strategically engaged with respect to causing or mitigating stress and 2. operationally based on real things present on the chessboard. In this way, our positional evaluation function will obtain insight not usually obtained by a computer chess program, and allow our machine to take positive, constructive action [browne02]. It is still an estimate, but the goal here is to focus our search efforts on likely moves in a positional style of play, and to evaluate positions from a more positional point of view.

What does the evaluation function look like for the proposed heuristic? We model (and therefore estimate) the positional pressure of our pieces, by following a two-step process:

1. We determine the *unrestricted future mobility* of each chess piece 3 moves into the future, then

2. We estimate the *operating range* or level of *engagement* of the pieces by determining the limiting factors or constraints that bound the unrestricted mobility.

The concept of using limiting factors is briefly mentioned [blanchard06] in the context of Systems Engineering. [lukey08] argues that an important aspect of cognitive appraisal is the extent to which stress-causing agents are perceived as controlled. Balancing processes such as constraints [anderson97] seek to counter the reinforcing loops created by a piece creating stress, which, if unconstrained, can potentially create even more stress (perhaps in combination with other pieces). Once we have identified the limiting factors, we can more easily examine them to discover which ones can be altered to make progress possible - these then become *strategic factors*.

The consideration of constraints is a part of the *decision protocol of Orasanu and Connolly* [orasanu93] and [plessner08] which also includes the identification of resources and goals facing the decision maker. We therefore reduce the bonus for accomplishing objectives (such as, attacking an enemy piece or defending a friendly piece) if the required moves can only be traced through squares that are *likely* to result in the piece being captured before it can accomplish its objective. We also reduce the engagement bonus for mobility traced through squares where the piece is attacked but not defended. We may use another scheme (such as probability) for determining stress-application reduction for piece movement through squares attacked both by friendly and enemy pieces where we cannot easily resolve whether or not a piece can trace mobility through the square in question (and therefore create stress). We think in terms of rewarding a self-organizing capacity to create stress out of the varied locations of the pieces and the constraints they face [costanza02].

We reward each piece for its predicted ability to accomplish strategic objectives, exert positional pressure, and restrict the mobility of enemy pieces, based on the current set of pieces on the chess board at the time we are calling our evaluation function. Using anticipation as a strategy [vanwezel06] can be costly and is limited by time constraints. It can hurt our performance if it is not done with competence. An efficient compromise between anticipative and reactive strategies would seem to maximize performance.

We give a piece an offensive score based on the number and type of enemy pieces we can attack in 3 moves - more so if unconstrained. We give a piece a defensive score based on (1) how many of our own pieces it can move to defend in 3 moves and (2) the ability to mitigate or constrain the attacking potential of enemy pieces. Again, this bonus is reduced for each move it takes to accomplish the objective. This information is derived from the influence diagram and simulation diagram we just calculated. Extra points can be given for weak or undefended pieces that we can threaten.

The proposed heuristic also determines king safety from these future mobility move maps. We penalize our king if our opponent can move pieces into the 9-square template around our king within a 3 move window. The penalty is larger if the piece can make it there in 1 or 2 moves, or if the piece is a queen or rook. We penalize our king if multiple enemy pieces can attack the same square near our king. Our king is free to move to the center of the board - as long as the enemy cannot mount an attack. The incentive to castle our king will not be a fixed value, such as a quarter pawn for castling, but rather the reduction obtained in the enemy's ability to move pieces near our king (the rook involved in the castling maneuver will likely see increased mobility after castling is performed).

The king will come out of hiding naturally when the number of pieces on the board is reduced and the enemy does not have the potential to move these reduced number of pieces near our king. We are likewise free to advance the pawns protecting our king, again as long as the enemy cannot mount an attack on the monarch. The potential ability of our opponent to mount an attack on our king is the heuristic we use as the basis for king safety. Optionally, we will consider realistic restrictions that our own pieces can make to our opponent's ability to move pieces near our king.

Pawns are rewarded based on their chance to reach the last rank, and what they can do (pieces attacked and defended in 3 moves, whether or not they are blocked or movable). The piece mobility tables we generate should help us identify pawns that cannot be defended by other pawns, or other pieces - it is this weakness that we should penalize. Doubled or isolated pawns that cannot be potentially attacked blockaded or constrained by our opponent should not be penalized. Pawns can be awarded a bonus based on the future mobility and offensive/ defensive potential of a queen that would result if it made it to the back rank, and of course this bonus is reduced by each move it would take the pawn to get there.

The information present in the future mobility maps (and the constraints that exist on the board for the movement of these pieces) allow us to better estimate the positional pressure produced by the chess pieces. From these calculations we can make a reasonably accurate estimate of the winning potential of a position, or estimate the presence of positional compensation from a piece sacrifice. This evaluation score also helps steer the search process, as the positional score is also a measure of how interesting the position is and helps us determine the positions we would like to search first.

In summary, we have created a model of positional pressure which can be used in the evaluation function of a computer chess program. [michalewicz04] reminds us that models leave something out, otherwise they would be as complicated as the real world. Our models ideally provide insight and identify promising paths through existing complexity.

[starfield94] emphasizes that problem solving and thinking revolve around the model we have created of the process under study. We can use the proposed model of positional pressure to direct the machine to focus the search efforts on moves which create the most stress in the position as a whole. For our search efforts, we desire a proper balance between an anticipatory and a reactive planning strategy. We desire our forecast of each piece's abilities to help us anticipate its effectiveness in the game [vanwezel06], instead of just reacting to the consequences of the moves.

By identifying the elements and processes in our system [voinov08], identifying the limiting factors from the interactions of the elements, and by answering basic questions about space, time and structure, we describe and define the conceptual model of our system.

16 Results

We have created software to demonstrate the proposed heuristic and now examine four positions to see if we can obtain a better positional understanding of how well the pieces are performing. John Emms [emms01], reached Figure 6 as white (black to move) with the idea of *restricting the mobility* of black's knight on b7.

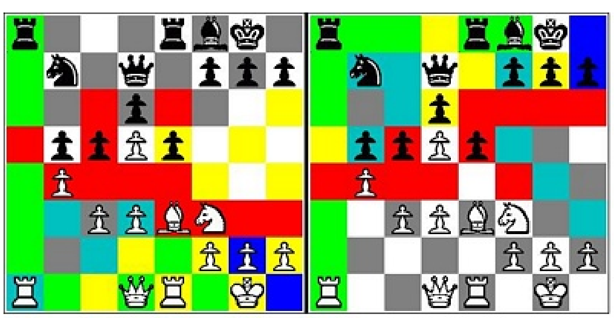

Figure 6: Emms-Miralles (Andorra, 1998) Constraint maps Legend: The left diagram identifies the possible constraints imposed by the white pieces, with red representing pawn constraints, yellow minor piece constraints, green rook constraints, blue-green queen constraints, and blue king constraints. The right diagram identifies possible constraints imposed by the black pieces. The white and grey squares represent the standard chessboard squares without constraints.

How fully engaged is this piece in the game? Let's see what the *influence diagram* and *simulation diagram* from the proposed heuristic show us:

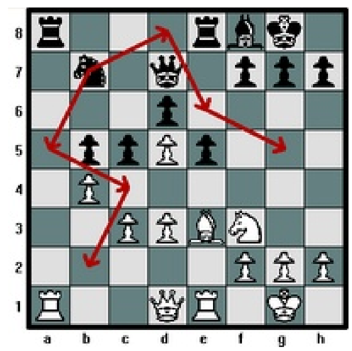

Figure 7: Emms-Miralles Tracing knight mobility from b7-a5-c4-b2 and b7-d8-e6-g5

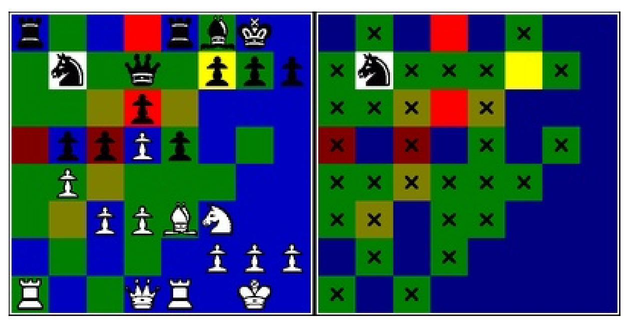

Figure 8: Emms-Miralles Influence Diagram and Simulation Diagram for Nb7

We generate the *constraint maps* as in Figure 6 in order to estimate the squares that the knight on b7 is likely to be denied access. We then apply the constraint maps to the individual vectors which make up the influence diagram as in Figure 7 to create the simulation diagram.

When a movement vector hits a constraint, future mobility through that square is constrained, and we use an "X" to indicate *constrained* mobility. We can see from the X's (denied potential mobility) of Figure 8 that the movement of the piece on b7 has been constrained. It is Emms' view that positional details like this one can be vitally important when assessing positions.

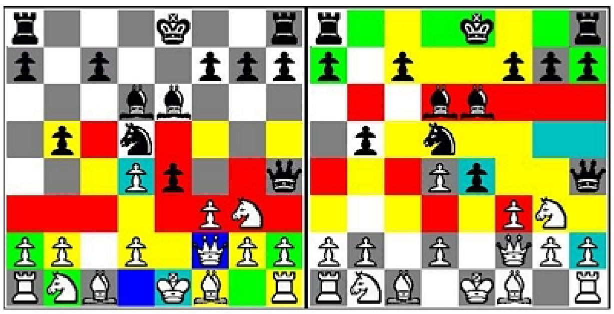

Figure 9: Constraint maps, white (left), black (right), Estrin-Berliner variation analysis (1965-68 corr.) after 12.Qe2 Be6 13.Qf2, Black to move

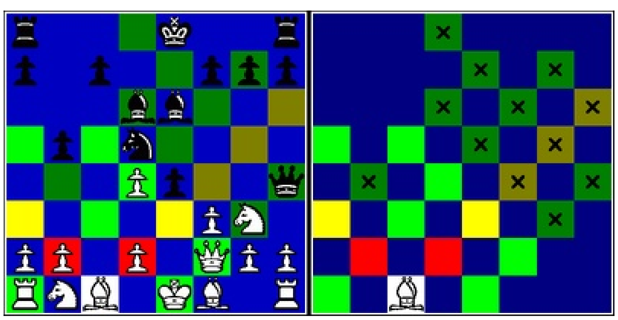

Figure 10: Influence Diagram and Simulation Diagram for Bc1

Figure 9 examines a sideline from Estrin-Berliner (1965-68 corr.) after the proposed improvement 12.Qe2 Be6 13.*Qf2*. How fully engaged is the white Bishop on c1? We generate the constraint maps and influence diagram as before in order to construct the simulation diagram. We see that the bishop on c1 can enter the game after moving a pawn out of the way, and become useful for creating and mitigating stress in future positions.

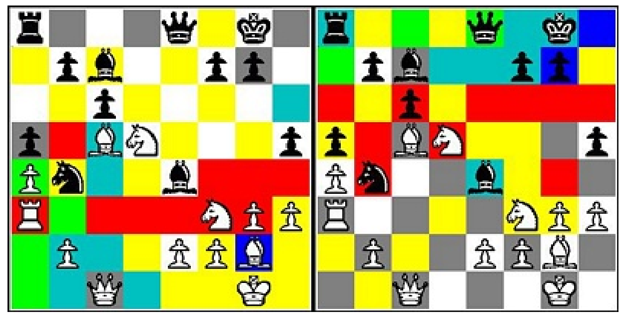

Figure 11: Constraint maps, white (left), black (right), Umansky-World correspondence game (2009)

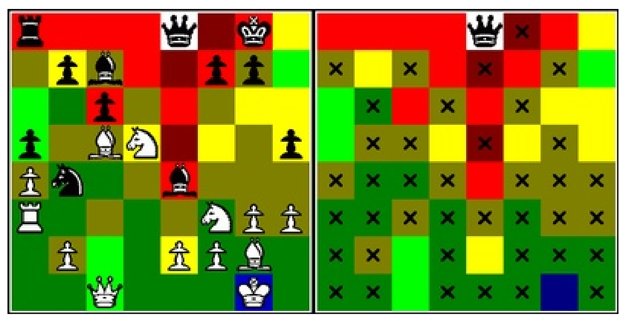

Figure 12: Influence Diagram and Simulation Diagram for Qe8

Figures 11 and 12 examine a position from the recent Umansky-World correspondence game. The constraint map gives insight to the controlling influences present on the squares, and the influence diagram/ simulation diagram for the Queen on e8 gives insight to what this piece can threaten in 3 moves. Note that this piece can influence square c1 via the difficult to find move sequence e8 to e6-h6-c1.

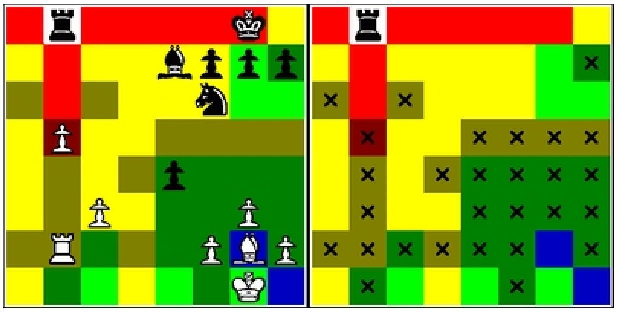

Figure 13: Influence Diagram and Simulation Diagram for Rb8, Levy-Chess 4.4, simultaneous exhibition, 1975, after 27.axb5

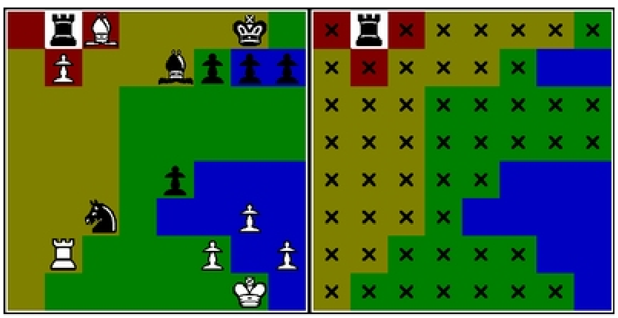

Figure 14: Influence Diagram and Simulation Diagram for Rb8, Levy-Chess 4.4, simultaneous exhibition, 1975, after 31.Bc8

Figures 13 and 14 shows how a machine can potentially recognize a trapped piece, with an example first identified and discussed by [levy76].

> The elements of a system and their interactions define the system structure

The computer can use the heuristic knowledge present in the influence diagram and simulation diagram to estimate the strategic potential or how *fully engaged* each piece is in the game. The maps are a useful holistic measurement of a capacity to produce stress in a position, and can be used as part of an oriented, vital system-level indicator to predict and manage the sustainable development of a position in a chess game.

17 Conclusions

> ...By answering the basic questions about space, time and structure, we describe the conceptual model of the system... Creating a conceptual model... very much resembles that of perception -Alexey Voinov

Ecosystems are working models of sustainable complex systems, and it is reasonable to study them for clues to the sustainable management of the human enterprise [jorgensen00]. We identify *systems thinking* and the *systems approach* as the theoretical basis for an evaluation function, shifting our focus from the parts to the whole. The use of approximate knowledge and the conceptualization of a network of interacting components is realized through a system dynamics model of stress, or positional pressure. The reality of the position on the chessboard is seen as an interconnected, dynamic web of relationships, with *oriented, cumulative stress* one driving force of change. We seek resilient positions and flexible, adaptive capacity to counter the effects of unknown positions that lurk just beyond our planning horizon. The concepts of *orientors and indicators*, *cumulative stress*, *constraints* and *virtual existence* allow us to effectively simplify the dynamic reality of each game piece interacting with every other game piece on the board - to the point where we can predict promising directions of exploration (via the mechanism of stress transformation) and identify the *accessibility space* [bossel98] of future sustainable development.

A model can be considered as a synthesis of elements of knowledge about a system [jorgensen00]. Our model of dynamic interaction presented in this paper ideally captures the dominant variables that control the transformation of stress [kossiakoff03], omitting the higher order effects that have a cost/benefit deemed to be overall not effective. No models are valid or verifiable in the sense of establishing their correctness [sterman00] [voinov08]. The question facing clients, academics, and modelers is not whether a model is true but whether it is useful as a basis for some action, which in our case, is steering search efforts (through the critical lines) in an exponentially growing tree of possibilities, in a way that allows a strong positional game of chess to be played. [miller07] advises, with regard to computational modeling, that we judge the quality and simplicity of the model, the cleverness of the experimental design, and examine any new insights gained by the effort. We should also ask ourselves if our model has just enough of the right elements, and no more. To be a good model, Miller is of the opinion that we have stripped phenomena down to their essentials, yet have retained enough of the details to produce the insights we require.

Ideally, our responsibility would be to use the best model available for the purpose at hand [sterman00] despite its limitations. We view modeling [sterman00] as a process of communication and persuasion among modelers, clients, and other stakeholders. Each party will judge the quality and appropriateness of any model using criteria which reflect on their role and perceived future benefits. This includes the time and effort involved in the unending struggle to improve the model to the point where its performance reflects what theory would expect of the particular approach. Modeling team A might not want to use a particular model due to significant time, money, belief, performance, and familiarity with their current approach. Team A might not even be interested in discussing new approaches. However, modeling team B might be looking for a new challenge, perhaps due to dissatisfaction with the current model, a belief in predicted performance, or perhaps due to a willingness to spend long hours and to engage with the types of problems suggested by the new approach. Team A might now become interested, seeing the preliminary success of team B.

Our attempts to reengineer the way machines play chess are, in the true spirit of reengineering [hammer95], throwing away current methods and starting over, but placing at the forefront of our design efforts the values and concepts of positional chess and Systems thinking. We acknowledge the dynamic and static elements of a chess position, and construct a sensor array which responds to a perception of stress in the position in order to orient our efforts to effectively navigate and explore an exponentially growing search tree. We adopt a Soft Systems Methodology - that is, we see the game position as complex and confusing, and we seek to organize the exploration of future consequences through the means of a learning system [checkland06].

The proposed heuristic offers insight on the ability of the chess pieces to create and mitigate stress and aims for a rich awareness of discriminatory detail [weick07] between promising and less promising positions. We agree with Donohew, et al., [donohew78], that *information seeking* must be a primary method for coping with our environment. Key components include the monitoring of structural tension created by the pieces as they mutually constrain each other and seek to satisfy vital system-level needs, and the attempt to create positions which serve as a platform for future success, in a future that is uncertain. All sustainable activities have to accept the natural system of constraints in which the investigated entity operates [jorgensen00].

Our evaluation centers on an array of vital diagnostic appraisals of the cumulative stress each side inflicts on the opponent's position, and the perceived mitigation of such stress. We aim to reduce our opponent's coping ability and adaptive capacity through oriented targeting of stress. The dynamic forces of change, acting over time and in a future we often cannot initially see, ideally transform the reduced coping ability of our opponent, our carefully targeted stress, and our resilient position full of adaptive capacity, to future positions of advantage for us. The entire purpose of modeling stress is to aid search focus - that is, we orient or focus our search efforts in priorities based on the changing amounts of stress in the position (and the results of vital diagnostic tests). We additionally monitor the stress that threatens to become real, having the property that [vonneumann53] has called "virtual" existence. Even if the threat does not materialize, it nevertheless has the capability to shape and influence the events that do become real.

We acknowledge that resilience is a distinguishing characteristic of any successful system [sanderson09] [gunderson10]. The creation of resilient positions full of adaptive capacity allows us to sharply and effectively postpone search efforts in less-promising lines with the low-risk promise of sufficient resources to handle the unknown future that lies beyond. We determine the level of resilience present in a position using a (heuristic) diagnostic test, such as the one proposed in this paper. We desire a methodology which emulates a productive thinking process, such as one envisioned by [hurson08].

From the highest level, we desire to model the cumulative dynamic stress present in the position so that we can effectively explore the possible directions of promising development. Our estimate of winning chances critically depends upon 1. exploring the promising and risk-mitigating paths and 2. correctly identifying those paths whose exploration of future consequences can justifiably wait until later. Inaccuracies in these two areas of classification will create a limit to overall performance, as we strategically attempt to compete against other agents with different and refined approaches to this same problem. We seek, as a strategy, to gain a sustainable edge over our opponent, and see the careful formation and execution of the strategic plan as the best and most productive way to accomplish this.

The proposed heuristic offers promise as a component of an evaluation function for a computer chess program, but should be used to steer a search process (such as forward and backward chaining) to effectively reduce search depth for lines deemed less promising. It also offers promise as a component of a chess tutor, as it can offer to students an insight into the ability of the pieces to accomplish strategic, positional objectives. The presented results demonstrate this insight for four test positions. Perhaps chess is more than just calculation [aagaard04], but the day may come sooner than we think when computers use heuristics to play a positional game of chess at skill levels equal to their current strong tactical play. Correspondence chess would provide the ideal testing ground for a positional heuristic.

We might borrow the words of economist Joseph Schumpeter (1883-1950) and theorize that chess is a game of Creative Destruction.

Future work will involve the development of an effective *search strategy* in order to maximize the usefulness of the proposed heuristic in a computer chess program. We will also investigate positions where the proposed heuristic does not work in providing insight and direction in search efforts.

Note: colored diagrams were produced by a computer program in HTML format and rendered in a Firefox web browser in a method similar to that used by the software program *ChessDiagrams* by Ambar Chatterjee.

Special thanks to all my friends at chessgames.com, through whom I continue to learn about chess.

18 Appendix A: Related Quotations

The analysis of general system principles shows that many concepts which have often been considered as anthropomorphic, metaphysical, or vitalistic are accessible to exact formulation. They are consequences of the definition of systems or of certain system conditions. - Ludwig von Bertalanffy, General Systems Theory, p.86.

a good model enables prediction of the future course of a dynamic system. - Bruce Hannon and Matthias Ruth

Perception, motivation, and values combine to create choice. - Joe Vitale

It's your decisions about what to focus on, what things mean to you, and what you're going to do about them that will determine your ultimate destiny. - Anthony Robbins

We are successful because we use the right level of abstraction. - Avi Wigderson

We can influence the future but not see it. - Stewart Brand

The mind will not focus until it has clear objectives. But the purpose of goals is to focus your attention and give you direction, not to identify a final destination. - John C. Maxwell

Of all the factors that contribute to adapting to change, the single most important factor is the degree to which individuals demonstrate resilience - the capacity to absorb high levels of change and maintain their levels of performance. - Mark Kelly and Linda Hoopes

Every piece of business strategy acquires its true significance only against the background of that process and within the situation created by it. It must be seen in its role in the perennial gale of creative destruction; it cannot be understood irrespective of it or, in fact, on the hypothesis that there is a perennial lull. - Joseph Schumpeter

It is not the strongest of the species that survive, not the most intelligent, but the one most responsive to change. - Charles Darwin

Resilience or some variation of this idea is a concept that is explicitly if not tacitly implicit in almost all explanatory models of behavior ranging from the biological to the social. It may be an inextricable part of the ways in which we define and explain not only human behavior but virtually all phenomena with variable outcomes. - Meyer Glantz and Zili Sloboda

any approach able to deal with the changing complexity of real life will have to be flexible... It needs to be flexible enough to cope with the fact that every situation involving human beings is unique. The human world is one in which nothing ever happens twice, not in exactly the same way. This means that an approach to problematical human situations has to be a methodology rather than a method, or technique... [Soft Systems Methodology] provides a set of principles which can be both adopted and adapted for use in any real situation in which people are intent on taking action to improve it. - Peter Checkland and John Poulter

I think that resilience is manifest competence de-

spite exposure to significant stressors. It seems to me that you can't talk about resilience in the absence of stress. The point I would make about stress is the critical significance of cumulative stressors. I think this is the most important element. - Norman Garmezy

No plan survives contact with the enemy. - Field Marshal Helmuth von Moltke

In many ways, coping is like breathing, an automatic process requiring no apparent effort... Is coping always a conscious process? ...we so often may repeatedly respond to a recurring stressor that we lose our awareness of doing so. - Charles Richard Snyder

What business strategy is all about; what distinguishes it from all other kinds of business planning - is, in a word, competitive advantage. Without competitors there would be no need for strategy, for the sole purpose of strategic planning is to enable the company to gain, as effectively as possible, a sustainable edge over its competitors - Keniche Ohnae

Rykiel (1996) defines model credibility as "a sufficient degree of belief in the validity of a model to justify its use for research and decision-making."... there is no use talking about some overall universal model validity; the model is valid only with respect to the goals that it is pursuing - Alexey Voinov

A principal deficiency in our mental models is our tendency to think of cause and effect as local and immediate. But in dynamically complex systems, cause and effect are distant in time and space. Most of the unintended effects of decisions leading to policy resistance involve feedbacks with long delays, far removed from the point of decision or the problem symptom. - John Sterman

everything in nature, everything in the universe, is composed of networks of two elements, or two parts in functional relationship to each other... The most fundamental phenomenon in the universe is relationship. - Jonas Salk, Anatomy of Reality

What is the core of the matter? Why should a machine not be an excellent chess player? Is the task insoluble in principle? ... No. The problem seems to be soluble... The machine may play chess badly, like a beginning amateur, but the machine is not guilty. Man is guilty. He has not yet succeeded in teaching the machine, in transferring his experience to it. What is involved in teaching a machine to play chess? - Mikhail Botvinnik

once you become aware of what means the most to you, you're less likely to put off something that's really valuable for something that matters much less... it's knowing the difference between what's important and what isn't that allows us to solve problems effectively. - Joy Browne

I understand very well that a weakness is only a weakness if it can be attacked, but you cannot put this into the evaluation function. It is a matter of search... To exploit them the program has to search. -Mathias Feist, Fritz programmer

Intelligence is the ability to acquire knowledge, and not the knowledge itself. - George F. Luger

Additional quotes:

http://mysite.verizon.net/vzesz4a6/current/id201.html

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