GOAL FORMULATION WITH EMOTIONAL CONSTRAINTS: Musical Composition by Emotional Computation

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A man, viewed as a behaving system, is quite simple. The apparent complexity of his behavior over time is largely a reflection of the complexity of the environment in which he finds himself.
Herbert A. Simon

Abstract

When an individual generates or improves upon a solution to a problem, the solution results from satisfying a planned set of goals. Successful plan construction and goal formulation requires knowledge of good solutions to previous encountered problems and/or memorable events that the individual functionally maps to the current problem. When determining which good solutions from previous problems map to the current problem, an individual can make selections based on context. This raises the following question: can *intelligence/creative thought* result from only the context searching of existing knowledge?

Systems, either human or artificial, develop specific patterns by which they address their environment and its respective challenges - we call these patterns habits. Habits are reflected in the mannerisms of individuals from all types disciplines such as: mathematics, computer programming, dancing, cooking, and composing music. The work presented in this paper assumes that habits develop within a system by forming opinions on how well specific solutions satisfy the disposition of the system when encountering a specific type of environmental stimuli. Thus as a system evolves and acquires multiple solutions to a given problem, the system will form habits in the use of these solutions based not just on problem context, but also the solution's ability to satisfy the current disposition of the system.

The application described in this paper is a system which composes music. The design of this system is based on work by Marvin Minsky [13] and the use of a weighted network of musical arti-facts (solutions). Each artifact is weighted based on its ability to satisfy a given (emotional) system disposition.

1 INTRODUCTION

Processes such as creative thought and learning result from achieving a structured pattern of goals. These goals evolve as artifacts from the environment within which a system exists. As an example, consider an infant's ability to navigate around a physical object, such as a sofa, while moving from a source location to a destination location. The goal *to get around a physical object* has become an artifact of the infant's movement within its environment. Historically, artificial systems have also depended on specific sets of goals to direct learning and problem solving within a given domain. A major difference between the infant and a mature artificial system is the higher degree of complexity by which the infant selects goals. The biological and environmental heritage of human cognition favors construction of meta-goals satisfying given emotional states. These meta-goals compile sets of problem solving goals composing partial mental states that the human system feels a goodness for in the context of its current meta-emotional-goal. These partial mental states are reconstructed from previous total mental states of memorable events. The selection [1] of memorable events is based on the known constraints of the current goal/problem.

The application presented in this paper, a system called WOLFGANG, began as a prototype examining several methods of goal formulation to artificially compose music. *The* **principal problem** *in the design of WOLFGANG was defining a successful theory of goal formulation to support system evolution.* The evolution of an intelligent system requires its perception of environmental events/phenomena and their transformation into useful knowledge, thus improving the system's performance within its environment. The system must be capable of determining what goals best classify the perception of an event and its coding in memory.

The theory of goal formulation used to design and implement WOLFGANG is based on the premise that *memory provides the ability to recreate partial states of mind and that the selection of these states is determined by the current disposition of the system.* Thus a system will formulate goals associated with specific emotional qualities that satisfy its disposition. The theory assumes that all systems are conceived with an innate set of primitives, some form of genetic code that defines the evolution of each individual system. These primitives propagate in a defined manner throughout the entire system controlling the behavior of the system and the perception of its environment.

2 K-LINES and E-NODES

WOLFGANG identifies two foci of interest. First, a theory of goal formulation directed by emotional constraints. Second, a new method to artificially compose music. Over the past two decades, a considerable amount of work has addressed the domain of computer composed music successfully. This has resulted in many syntax-oriented the-

*The work reported here is based on the author's personal graduate research. It is not part of any existing Bellcore work.

[1] The selection process is guided by such search strategies as analogy, reformulation, heuristics, and association.

ories of musical composition by computer and has raised an important question. Do such systems truly compose music, or are they really music generators? While it is essential to compose music by some well-formed theories of grammar [9; 14], these theories fail to capture the essence of music, its ability to communicate emotion - the semantics of musical sentences. WOLFGANG's use of emotional computation, K-lines, and musical grammars presents a new direction for composition by computer.

A principal influence in the design of WOLFGANG is Marvin Minsky's "Society of Mind" (SOM) theory [2] [13]. The theory describes the behavior and cognition of a system by the dynamic relationships of linked semi-intelligent agents called K-lines. The theory goes on to explain that sets of K-lines form societies of agents providing specific mental functions and that these societies and/or agents can dynamically form multiple connections (K-lines) with other societies and/or agents to provide many different types of intelligence. It is the activation of sets of K-lines (societies of agents) that compose partial mental states. A total mental state is composed of several partial mental states active at a single moment in time. Further, system evolution is supported by constructing new K-line connections within and/or between these partial mental states.

A key component in WOLFGANG's architecture is a network of K-lines. The composition of the K-line network consists of many heterarchical societies of agents. Eventually, these societies decompose to individual agents which in turn decompose to an innate set of primitives that defined WOLFGANG at its inception. [3] These primitives, called *E-nodes* (Emotional Nodes), are fundamental structures that qualify the emotional characteristics in perceiving the simplest elements of a given domain/environment.

For example, in the domain of musical composition, an E-node defines the emotional qualities of such auditory stimuli as musical modality, single harmonic structures, harmonic progression, amplitude, tempo, rhythm and musical intervals. Metaphorically, E-nodes serve as the system's emotional genetic code.

Each E-node contains a set of real number weights ranging from zero through one for each of the following emotions: happy, sad, anger, and soul-searching. These weights define the emotional character of a given stimuli and are constant for the life of the system. The E-nodes within WOLFGANG serve as a lexicon defining the emotional characteristics of individual agents in the K-line network. Thus, as WOLFGANG evolves, the properties of the E-nodes propagate through-out the entire system contributing to the perception of environmental stimuli and the creation of K-lines to represent more complex societies of musical agents with their respective emotional weights.

If E-nodes define the emotional capacity of such musical atoms as tempo, then what phenomena justifies an E-node? Psychological research in music addresses the extent to which the construction of a melody is determined by factors *extrinsic to music* - in particular, by the natural pitches of the harmonic series and their effects on and within the ear. For example, musical idioms of the world as a whole demonstrate a high salience for the octave, perfect fifth and major triad due to the harmonic series [7; 1; 2; 3]. Thus, the idea is to define a set of E-nodes that are innate throughout all cultures of music.

As an example, repertoire for the kyoto, sitar, balalaika, lute and guitar all demonstrate a high salience for octaves, perfect fifths, perfect fourths, cycles of fifths, and cadences built from perfect fifths. These musical components are strong and support a sense of finality. Thus, they are useful in constructing resolution from tension or climax. Other components such as major/minor seconds, minor thirds, augmented fourths, minor sixths and minor sevenths are less stable and are useful to generate the tension or climax.

Time trajectories are another important property in music perception. Faster tempos support higher levels of energy while slower tempos perform the inverse [13; 3]. Another consideration is the spatial proximity of pitches in a melodic sequence and its role in the effectiveness of memory to retain the specific melodic sequence. Studies have shown that smaller size intervals are processed more effectively [4; 5]. This is an important consideration for motivic development.

3 APPLICATION OVERVIEW

The discipline of musical composition requires balancing in parallel the goals of many distinct musical components [4] that contribute to the highly complex structure of a musical work. Each goal considers the structural, aesthetic and functional constraints of its respective musical component based on the well-formedness of a musical grammar for each component. WOLFGANG was designed to formulate goals and sub-goals to meet the respective constraints of each musical component and to formulate meta-goals to negotiate the collaboration of these diverse component goals during the composition process.

A typical session with the application allows the user to request WOLFGANG to compose a musical composition that communicates a specific emotion. The selection of emotions is limited to *happy, sad, anger,* and *soul-searching.*

Currently, the musical components that contribute to the emotional character of a given composition composed by WOLFGANG are melody, harmonic progression, rhythm, tempo, and motivic development. So as to limit the class of problems supported, the length, meter and form for all compositions are static and serves as a skeletal structure for the planning functions in WOLFGANG.

Each composition is exactly sixty-four measures in length with a meter of four-four time and follows a quasi Sonata Allegro musical form. The Sonata Allegro form is partitioned into three sections: an Exposition section of 32 measures with a modulation, a Development section of 16 measures with a modulation back to the original key and/or modality, and a Recapitulation section comprised of the final 16 measures in the original key. A more detailed view of this skeletal structure is as follows:

- The first sixteen measures of the Exposition section states the entire motif (theme) of the composition

[2]The "Society of Mind" theory is the evolution of Minsky's K-line theory.

[3]The inception of WOLFGANG is that moment in time before the system began to perceive its environment and learn.

[4]Examples of musical components are melody, rhythm, harmonic progression, motivic development, and form.

and then motivically develops the motif and/or subsections of it with slight variations.

- The second sixteen measures of the Exposition section is dedicated to pure motivic development of the motif. The methods of development during this sixteen measure section are allowed greater freedom. This section will then conclude with a modulation to another key and/or modality.

- The Development section, the next sixteen measures, continues the motivic development of the motif in the new key and/or modality with the same amount of freedom allowed in the second half of the Exposition section. The Development section will then close with a modulation to the original key and/or modality of the Exposition section.

- The Recapitulation section begins by restating the original motif. The remainder of the Recapitulation is then composed of several of the *most memorable* motivic developed artifacts from the Exposition section. This is accomplished as follows: *During a composition session, feedback facilities allow the application to monitor its work. As phrases of musical sentences are constructed, they are weighted as to their success in satisfying the current disposition of the system.* So, once the original motif has been restated in the opening measures of the Recapitulation, WOLFGANG then cuts and pastes those musical phrases with the highest weight values from the Exposition to complete the composition.

The physical location of cadences is every four or eight measures depending on the length of the motif being two or four measures respectively. The system will then maintain complete symmetry of musical phrases by maintaining a constant distance between cadences throughout the composition. From a user perspective, a typical composition session with WOLFGANG is partitioned into three phases:

- *Priming:* The user performs three tasks, (1) enters a seed/musical motif (a linear set of musical tones and the duration of time for each tone), (2) selects the emotional quality that the composition should communicate, and (3) defines the behavior of WOLFGANG during the composition session as a type ranging from conservative to aggressive. The behavior of the system during a session directs goal formulation to try ideas/methods ranging from conservative/established to aggressive/new.

- *Evaluation:* WOLFGANG evaluates the user supplied motif to determine a characterization of the motif that best matches the desired emotion of the completed composition. This entails parsing the motif into simple elements consisting of several notes each. The selection of these elements is based on a melodic grammar and the emotional characteristics of specific groupings of notes that best communicate the emotion selected by the user. WOLFGANG then examines the combinatorics of harmonic progressions for the parsed motif and defines several options of harmonic progressions implied by the motif that capture the desired emotional qualities.

- *Composition:* WOLFGANG composes the musical work.

4 SYSTEM ARCHITECTURE

WOLFGANG's architecture is composed of the following elements: (1) a K-line network, (2) a scheduler, (3) a blackboard, (4) several feedback loops, (5) a logfile, and (6) a user-interface.

4.1 K-line Network

The K-line network is partitioned to into two parts, with each part providing a distinct function. One portion of the net, the methods-net, serves as a composer's tool box. The methods-net contains several different method-societies of agents defining such compositional methods as cadence, transposition, and motivic development. It is important to note that **the methods-net is composed of facts, not rules.** The other portion of the K-line net, the facts-net, defines explicitly such musical *facts/artifacts*, as sets of intervals, rhythmic patterns and harmonic progressions.

Each method-society in the methods-net is constructed by interconnecting many smaller societies and/or individual agents defining specific types of methods. For example, the method-society defining motivic development is composed of many smaller societies defining types of development, such as inversion, retrograde, and elongation. K-lines interconnect the method-agent with each of its type-agents. In turn, each type-agent is represented by one or more K-lines to specific musical facts/artifacts in the facts-net. These K-lines to the facts-net define an explicit musical artifact: such as an exact set of intervals to compose a musical phrase to satisfy the respective type-agent, who in turn then satisfies the respective methods-agent, which in turn satisfies the system disposition. This will be presented in more detail shortly.

There is one major difference between agents in the methods-net and the facts-net. Agents in the facts-net are assigned emotional weights when they are created. The agents in the methods-net only inherit emotional weight values temporarily. When a given set of K-lines are active, the agents in the methods-nets temporarily inherit the weights of the explicit musical artifact most active in the facts-net which they are connected to.

4.1.1 Implementation of K-lines and E-nodes

Within WOLFGANG, E-node's are implemented as frames. The first slot in the frame explicitly denotes the type of musical component/stimuli. For example the component could be a specific tempo setting or the interval between two pitches. The next four slots hold the four respective emotional weights. These weights are assigned at the inception of the system and remain constant during its life. Each E-node maintains all four emotional weights since a given stimuli might be capable of communicating several different emotions. Each E-node is then associated with a specific group of E-nodes based on its respective function. [5] These E-node groups are implemented as lists.

[5] Examples of group functions are tempo, intervals of two pitches and modality.

It is important to remember that an agent with a set of data links is a K-line and that the set of links interconnect sufficient data to allow the K-line to represent a useful fact of knowledge. Each K-line results from constructing connections for one of the following cases: (1) between sets of E-nodes, or (2) between E-nodes and other agents/societies, or (3) between sets of agents/societies.

Each K-line/agent is implemented as a frame, known a K-line-frame (KF), and is stored as a slot value in another frame called a musical-component-frame (MCF). The first slot value in a MCF denotes the type of musical component. The remaining slots in the MCF are called KF slots.

Each KF slot defines a given K-line associated with the respective musical component. The number of KF slots is dynamic since new K-lines are always possible. The first slot in a KF defines the respective K-line. All the respective links that compose the K-line are stored as a list in this first slot.

The remaining four slots in a KF denote the four emotional weights provided by the respective K-line. Each emotional weight is a tuple - where the first variable is a quasi-static weight (QW) and the second is a dynamic weight (DW). These weights are used to control the firing of K-lines. When a K-line is first constructed each emotional weight is computed and assigned to both variables in the tuple. There are two cases to consider when computing emotional weights:

- If a K-line connects only one E-node frame with a MCF, then the respective KF weights are inherited from the E-node and the K-line is considered a very-low-level agent.
- If the K-line is connected to several E-nodes and/or other agents/societies, then the averaged weight of all the connections for each type of emotion is assigned to each of the respective KF weights. If a majority of the connections are to E-nodes, then the K-line is considered a low-level agent.

Each time the system is initialized for a composition session, the DW of each tuple is assigned the value of the QW. The DW is used in determining which K-line offers the best solution to satisfy a given meta-emotional-goal.

During a session, the DW will change based upon events in the K-line net. For example: the current system goal is to fire the K-line with the highest *sad* DW which addresses the musical syntax of the current problem. Once this K-line has fired, its sad DW will be decremented. This allows other K-lines a chance to fire. Eventually, the sad DW of this K-line will be incremented back to the value of the QW.

Incrementing this DW will occur each time the same type of problem is addressed. Of course, the system's feedback facilities may flag the use of this K-line as a very positive event and strongly recommend to the system scheduler that this K-line be fired again to address this type of problem the next time it occurs. The scheduler will then assign the value of the QW to the DW.

The QW serves as a control weight throughout a composition session, but over time (many sessions) the QW might change. The system maintains a logfile of the last twenty sessions. If a given K-line shows a pattern of high or low usage, then the system will readjust the QW accordingly, thus allowing the system to adjust its musical opinion - to evolve.

4.2 Scheduler

The scheduler conducts the flow of events within the system so that they satisfy the system's current disposition. This implies that the disposition might change during a composition session. As an example assume WOLFGANG is composing a happy composition. For the first 40 measures of the composition, WOLFGANG's disposition is to compose happy, but a K-line in the method-net defining that a small change in the emotion of the music is needed just fired. In satisfying this new goal, WOLFGANG's disposition is to compose the next eight measures of the composition as slightly angry, then change its disposition back to happy for the remaining measures of the composition.

To satisfy the system's disposition, the scheduler constructs goals, evaluates the network, activates K-lines, builds K-lines, computes/adjusts weight values, monitors feedback loops/logfile, and manages global data stored on the blackboard. Since the scheduler is responsible for so many functions, it's no surprise that a composition session runs eight to ten minutes. WOLFGANG is currently a stand alone system, but its modular architecture provides for future integration with other systems to distribute the processing of a session and add on more features. This application is an excellent candidate for parallel hardware due to the parallel nature of the K-line network.

4.3 Blackboard

The blackboard provides global information of all concurrent/parallel events within the system. Output from evaluating the user supplied motif and the actual composition itself are stored on the blackboard. This information is stored in several interconnected structures.

As an example, I will present the internal representation on the blackboard of the user supplied motif. The pitches and rests from a user supplied motif are assigned as leaves in a *Time Span Tree (TST)* as described by Lerdahl and Jackendoff [9]. Important sub-motifs within the motif that support the desired emotion of the completed work are marked as useful elements for the composition process. The location of each marked leaf is added to a list of *good musical ideas for motivic development.* Thus this Motivic Element List (MEL) is a list of links into the TST.

The final structure, the List of Harmonic Links (LHL) is a list of nested lists. The outer most list defines multiple harmonic progressions that support the entire motif and the desired emotion of the composition. Each expression in the list defines a specific harmony which is linked to a specific leaf in the TST. When multiple harmonies support the same leaf, then the respective expression for that leaf when evaluated returns a list of expressions with each expression defining a valid harmony for the respective leaf.

The output from the composition session is stored in the same manner. The blackboard also stores output from the feedback loops, the current disposition of the system, the desired emotion type for the composition, and pathnames of activated K-lines in the network.

4.4 Feedback Loops

The feedback loops provide WOLFGANG with the ability to self-evaluate the artifacts of its performance during a composition session. WOLFGANG can then mark for future use during the composition session those artifacts that compute high emotional scores while satisfying the current disposition of the system. The feedback loops are implemented as background processes that send status messages to the scheduler that an interesting event has occurred and then post the blackboard with data concerning the event. The feedback loops monitor both the session's output on the blackboard and the logfile.

4.5 Logfile

While WOLFGANG's compositional style has a distinct signature, the logfile insures that each composition composed is distinct. The logfile provides information of previously composed works, thus WOLFGANG can avoid the excessive repetition of musical artifacts by reviewing its composing habits during a session. The logfile consists of trace data from the last twenty sessions.

4.6 User-Interface

The user-interface supports interactive learning exercises for the user to instruct WOLFGANG, the priming of a composition session, the tracing of the composition process, and the generation of the finished musical score. Currently the interface is a simple interactive shell to enter commands, but future work should improve upon this facility.

5 GOAL FORMULATION

During a composition session, goal formulation is first directed by the context of the problem. Further pruning is then achieved by defining the desired emotional characteristic that satisfies the current disposition of the system. This results in the formulation of a goal to construct a set of musical component agents, [6] that satisfy the prescribed emotional characteristic.

Once a goal is defined, those K-lines that best match its syntax and are weighted the highest for the current desired emotion meeting the current system disposition get fired. This process repeats recursively for each sub-goal until the artifact (musical component agent) of the respective sub-goal is determined to be an atom.

To demonstrate the goal formulation process, let us examine the following example of system events. We will assume that the system is about to compose the next musical phrase of the composition beginning at measure seventeen (second half of the Exposition). The user has (1) entered a four measure motif, (2) requested a happy composition, and (3) stated that the system's behavior is conservative. Within the K-line net, the method-net has fired K-lines noting the cadence of the last musical phrase. Also the current disposition of the system is (still) happy. Now the stage is set.

[6] An example of a musical component agent is a specific harmonic progression or a specific melody (linear set of musical intervals) or a specific type of cadence.

The firing of the K-line noting the last cadence invokes a planning goal for musical form (non-emotional goal) to determine what to do next. The scheduler determines from the TST of the current composition on the blackboard that the next musical phrase begins the second half of the Exposition, which calls for more complex motivic development. The scheduler then constructs a goal to determine how to develop the motif at this temporal point in the session/composition by firing the method-net K-line for motivic development.

The firing of this K-line propagates other sub-goals such as: (1) How long will the next phrase be? (2) How should the next phrase be bridged from the cadence of the previous phrase? (3) What type of motivic development is best? We will simplify this example by only examining the selection of the Motivic Development Type (MDT).

In order to select a MDT, the scheduler must be aware of the current temporal moment in the composition - for example: if a cadence is near at hand, then the options are limited. The scheduler must also pay close attention to the preceding phrase and cadence so as to maintain a smooth transition between phrases. Since in our example we are at the beginning of a phrase, we are not limited by a cadence within the next measure or so. As a result of these findings and the firing of the MDT K-line, all K-lines for Specific Type of Motivic Development (STMD) connected to the active MDT in the method-net are considered. Remember - one of our current goals is: *what type of motivic development to use.*

The scheduler reviews each STMD K-line with its emotional weight while in (virtual) parallel determining which sub-motif from the MEL on the blackboard to use for the development. The scheduler will then fire the STMD with the highest weight that satisfys the system disposition to compose happy.

Let us assume that the selected STMD calls for repetition of the sub-motif selected from the MEL, but with an alteration of the interval between the first and second notes in the sub-motif. The firing of this K-line defines a new goal: what interval should be used? This new goal will be satisfied by firing one or more K-lines in the facts-net. The selection of interval is dependent on many other parallel events (other active K-lines) for such societies as harmonic progression and rhythm. Let us assume for the sake of simplicity, that a specific harmonic progression and rhythm have been defined for this current musical phrase. Once the goal to define a specific interval is instantiated by the firing of the respective STMD K-line, multiple K-lines defining specific intervals in the facts-net are considered by the scheduler.

These specific K-lines are selected by syntax first: find intervals that *slightly* change the original interval of the sub-motif and that complement the selected harmony and rhythm. From this set of K-lines, the scheduler will then fire that K-line with the highest weight matching the current system disposition. By firing this respective K-line for a specific interval, which is also defined as an E-node, we have reached an atom - thus recursion ends. It should be noted that if the K-line search fails to satisfy a given goal, then backtracking will occur.

I would like to point out that the recursive K-line paths activated in this example are built from several different partial mental states. Extracting partial mental states from previous total mental states of memorable experiences is what Minsky defines as levels, level bands, and fringes in his SOM theory.

6 SYSTEM EVOLUTION

The agents for each type of musical component are the result of environmental stimuli during WOLFGANG's evolution. These stimuli are perceived/learned and stored as the memorable events (agents) of a given mental state. The construction of mental states, both partial and total, is based on Minsky's K-line theory of memory [12]. Further, during the perception/learning process, the memory encoding of memorable events includes the evaluation and assignment of sets of emotional weights defining the emotional qualities of the respective memorable events. [7] This provides a facility to compute the emotional qualities of different partial mental states composed of given agents. The evaluation and assignment function of emotional weights to memorable events (agents) is computed from the respective E-node and K-line emotional weights of the current mental state.

System evolution occurs whenever K-lines are created and/or altered within WOLFGANG. These changes in the K-line network result from either inductive learning sessions with a teacher or by experiment/discovery during a composition session.

During an inductive learning session, a teacher presents a learning example and directs its use by the system [10; 11]. Once the example has been learned, the system's mental state of this memorable event results in a change of the K-line network, thereby completing the *learning from instruction* phase of the inductive learning process. Using generalization rules of musical grammars, WOLFGANG will then attempt to create and/or alter K-lines within the network to extend the scope of generalized concepts constructed from the learning example to include other instances.

Learning by discovery is accomplished by formulating analogies which serve to connect weakly/never connected artifacts to determine new useful results [6; 8]. Discovery learning occurs when WOLFGANG's behavior is selected by the user to be aggressive during a composition session. WOLFGANG will experiment by formulating analogies to connect weakly/never connected K-lines (musical agents) to determine their usefulness. When this occurs during a composition session, a K-line is created and emotionally weighted defining the connection. The new agent(s) from this K-line are then used in the respective portion of the musical work. A flag is set to mark the use of these new agent(s) and require WOLFGANG to evaluate their impact during the remainder of the composition session. Should a negative impact occur, WOLFGANG will backtrack, purge the newly created K-line and attempt a more conservative solution, otherwise, the K-line is retained in the network due to a positive discovery.

[7] The assignment of multiple emotional weights is allowed since a musical agent may communicate several emotions. Selection of emotions is limited to happy, sad, anger, and soul-searching on a scale of real numbers from zero to one.

7 CORRECTNESS

The correctness of WOLFGANG's computation based on disposition is dependent on the correct propagation of emotional weights within the K-line network. Evaluation of the correctness required the creation and evolution of several individual (WOLFGANG) systems. Each system followed a distinct evolutionary path of learning exercises and composing sessions. The objective was to *examine the growth of K-lines* within each system and to *monitor the trace files* during the composing sessions of each system.

The examination of K-lines revealed that their emotional weights correctly characterized their respective emotions based on the emotional-genetic code defined in the E-nodes. The K-line examination evaluated the creation/altering of K-lines and the summing/averaging of weights to define individual agents and societies of agents within the network.

The trace files record the sequence of actions performed by WOLFGANG to formulate goals in order to satisfy a given disposition. The examination of trace files served to determine if WOLFGANG had formulated goals expressing a given emotion that did not match its disposition. Did the achievement of a goal result in composing a sad musical artifact while WOLFGANG believed the artifact communicated happiness. The data collected in the trace files demonstrated that WOLFGANG had successfully formulate goals to match dispositions.

A second evaluation of WOLFGANG is its pragmatic use. After a year of prototyping, several systems have been deployed over the past six months to complement the work of several (human) composers. [8] WOLFGANG provides the composer with a rich set of options for the motivic development of a given musical theme. Thus, allowing the composer to quickly examine and plan multiple strategies while concentrating on a given creative thought. This feature is of great value to composers and producers working under time constraints in the fields of advertising, television, records, and film. To date, the users have found the application useful and have consistently agreed that WOLFGANG's compositions communicate the intended emotional quality requested.

8 DEPLOYMENT/BENEFITS

Currently, two composers in the field of advertising and one composer/producer are using WOLFGANG in their work environment. The payback and benefits provided by their use of WOLFGANG are the following: (1) WOLFGANG provides a means to save valuable user/composer time when experimenting with a musical idea and (2) WOLFGANG can be used to stimulate creativity. These two artifacts of the application are exceedingly valuable to a composer.

In a business environment, a composer must continually be creative under varying time constraints. Many composers seldom have the time or freedom to wait for creative thoughts to occur, realistically, their creative output must meet specific project windows. WOLFGANG serves as an

[8] A total of eighteen months have gone into the prototyping and deployment of WOLFGANG.

excellent collaborator/catalyst when a composer's creativity is in a search mode and time is an important factor.

For example: a composer may use WOLFGANG to compose multiple compositions based on a specific motif/theme-song of a given customer for an advertising jingle with a given emotion. WOLFGANG will quickly compose/provide the composer with a combination of different ways to develop/experiment with the motif. Some of these musical examples provided by WOLFGANG might even present new musical ideas that the composer might never have considered or have overlooked - thus stimulating creative thought.

WOLFGANG began as a graduate research project in August 1987 and has since evolved into the current system presented in this paper. During the first year of work, several prototypes were developed. In May of 1988, the current system architecture based on the K-line theory was implemented replacing a rule based system architecture. This new design allowed WOLFGANG to encode knowledge without having to hardwire new rules into its memory - resulting in a minimal set of explicit rules in an evolving system. From May through August of 1988, this new architecture was further refined. By September of 1988 the application was ready for trial use.

During the design and development of WOLFGANG, I served as both the knowledge engineer and domain expert. Prior to my affiliation as a member of technical staff with Bellcore (Bell Communications Research) and graduate studies in computing science, I was a professional composer/musician with such credits as undergraduate studies at Juilliard/Manhattan Schools of Music, world concert tours, and employment as a staff composer for United Artist.

During the first year of prototyping, an average 15 to 20 hours a week were spent on research/reading, design and implementation. Since WOLFGANG was a personal research project, prototyping was limited to evenings and weekends - I would estimate that prototyping under normal working hours would have taken less then five months.

From September of 1988 to present, work with WOLFGANG has taken two parallel paths: (1) investigation of having WOLFGANG review one of its completed compositions with the purpose to search and plan possible improvements to the completed work and (2) allowing other composers to work with the current application.

There were two objectives in deploying WOLFGANG for use by other composers. First, determine how well does the application work for others, and second, what types of output from WOLFGANG result from its use and evolution in different environments/cultures. As previously mentioned, all the users have found the application useful and correct in composing works of a given emotion for a specific motif. As for the culture issue, the compositions did reflect the (training) habits of the respective trainers/composers.

The deployment of WOLFGANG requires that the user/composer initialize the emotional properties defined in the E-nodes and then interact with learning exercises for the system. Depending upon the level of musical maturity required by the composer, the deployment time can range from several days to several weeks. To improve the deployment capability of the application, work over the past six months has focused on improving the user interface to (1) initialize E-nodes, (2) train the system, and (3) run composing sessions. This work also included the porting of code to run on micro-computer hardware. During this time period, the work averaged between 5 to 10 hours a week.

9 CONCLUSIONS

I believe that the signature of a given composer, the semantics of his/her/its music is reflected in the frequent patterns of activated K-lines that occur over a composers lifetime. *These patterns are a reflection of the composer's disposition and environment.* The aim of WOLFGANG is to allow its disposition (and sub-emotions) to compose the music. The disposition formulates sets of meta-emotional-goals which recreate partial mental states (activated K-lines) providing specific emotional qualities to match and satisfy the disposition and its goals.

The work presented in this paper is just a beginning for computation based on disposition. Future work will expand the concept of goal formulation with emotional constraints and develop new applications in other domains. Interest has already been expressed to use some of the concepts which implemented WOLFGANG for the design of new multi-media tools/interfaces. Several disciplines to be considered are animated graphics, scripting for multi-media services, color selection from workstation/windowing color maps for hypermedia browsing, story-telling for interactive video and navigation systems. I believe that WOLFGANG demonstrates an innovative approach to goal formulation and the artificial composition of music. Further, WOLFGANG provides a working model of computation to study the cognitive aspects of goal formulation for a creative process.

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