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Preface

This volume contains the conference proceedings of the 29^{th} Annual German Conference on Artificial Intelligence (KI 2006) held June 14–19, 2006 at the Convention Center in Bremen, Germany. KI 2006 was organized under the auspices of the AI section of the German Informatics Society (GI), a member society of the European Coordinating Committee of Artificial Intelligence (ECCAI).

This year, we stepped out of our regular pattern of holding the conference at the end of the summer as we decided to accompany the RoboCup 2006 competitions at the Bremen Fair and Convention Center with our scientific AI conference. To avoid an unusually early submission deadline that would have competed with other major AI conferences, we decided to publish post-conference proceedings. We received a large number of excellent contributions: 112 papers from 25 countries were submitted. In a thorough peer-review process, the international Program Committee selected 29 full papers that are published in this volume. The contributions cover a range of topics from ontologies to cognition and emotion, from spatial and spatio-temporal reasoning to machine and robot learning, and from analogies to natural language.

Two speakers were invited for keynote lectures: Ramon López de Mántaras presented his work on applying AI methods to the transformation of musical performances and Ulrich Furbach spoke about applications of automated reasoning. Their written contributions to these topics are also published in this volume.

In addition to the regular conference sessions, six workshop proposals and nine poster contributions were accepted for the conference. The workshop sessions were held on June 14 and on June 19, 2006. The contributions to these sessions were published in separate proceedings volumes.

The month and year of our conference mark the 50^{th} anniversary of the 1956 Dartmouth conference, which is considered the birth of artificial intelligence research. On the occasion of this anniversary, eight special guests — Marvin Minsky, Aaron Sloman, Wolfgang Bibel, Jörg Siekmann, Wolfgang Wahlster, Sebastian Thrun, Hiroshi Ishiguro, and Simon Schmitt — were invited for the public symposium "50 Years AI" on June 17, 2006 after the regular conference sessions. The public symposium was moderated by Wilfried Brauer and presented highlights of AI research from the past 50 years as well as visions for the next 50 years to a scientifically interested public audience. The event was streamed live on the Internet and enabled interested people all over the world to follow the presentations and discussions.

Many individuals and teams contributed to the visions and the realization of this conference. We would like to thank the members of the Program Committee for their careful reviews and their excellent comments to the authors; referee comments are extremely valuable to the authors and constitute an important element to progress in science. We would like to thank the discussants of the

golden anniversary celebration for their visions and ideas, in particular Herbert Stoyan for first suggesting the idea. We would also like to thank the members of the various Organizing Committees for their productive and successful contributions, the valuable advice they provided, and the smooth interactions. In particular, we thank our local Chair, Eva Räthe, for her tireless dedication to this project, Marion Stubbemann for her support and assistance, and Sven Bertel for his energy and help with public relations.

The work of the Program Committee and the preparation of the conference proceedings were greatly simplified by Andrei Voronkov's excellent `EasyChair` system.

September 2006

Christian Freksa
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Special Event. 50 Years Artificial Intelligence

Expressivity-Preserving Tempo Transformation for Music – A Case-Based Approach

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Abstract. The research described in this paper focuses on global tempo transformations of monophonic audio recordings of saxophone jazz performances. More concretely, we have investigated the problem of how a performance played at a particular tempo can be automatically rendered at another tempo while preserving its expressivity. To do so we have develppoped a case-based reasoning system called *TempoExpress*. The results we have obtained have been extensively compared against a standard technique called uniform time stretching (UTS), and show that our approach is superior to UTS.

1 The Problem of Generating Expressive Music

It has been long established that when humans perform music from score, the result is never a literal, mechanical rendering of the score (the so-called nominal performance). As far as performance deviations are intentional (that is, they originate from cognitive and affective sources as opposed to e.g. motor sources), they are commonly thought of as conveying musical expressivity, which forms an important aspect of music. Two main functions of musical expressivity are generally recognized. Firstly, expressivity is used to clarify the musical structure (in the broad sense of the word: this includes for example metrical structure [Sloboda, 1983], but also the phrasing of a musical piece [Gabrielsson, 1987], and harmonic structure [Palmer, 1996]). Secondly, expressivity is used as a way of communicating, or accentuating affective content [Juslin, 2001; Gabrielsson, 1995].

An important issue when performing music is the effect of tempo on expressivity. It has been argued that temporal aspects of performance scale uniformly when tempo changes [Repp, 1994]. That is, the durations of all performed notes maintain their relative proportions. This hypothesis is called relational invariance (of timing under tempo changes). However, counter-evidence for this hypothesis has been provided [Desain and Honing, 1994; Timmers et al., 2002], and a recent study shows that listeners are able to determine above chance-level whether audio-recordings of jazz and classical performances are uniformly time stretched or original recordings, based solely on expressive aspects of the performances [Honing, 2006]. Our approach also experimentally refutes the relational

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invariance hypothesis by comparing the automatic transformations generated by *TempoExpress* against uniform time stretching.

2 TempoExpress

Given a MIDI score of a phrase from a jazz standard, and given a monophonic audio recording of a saxophone performance of that phrase at a particular tempo (the source tempo), and given a number specifying the target tempo, the task of the system is to render the audio recording at the target tempo, adjusting the expressive parameters of the performance to be in accordance with that tempo.

TempoExpress solves tempo transformation problems by case-based reasoning. Problem solving in case-based reasoning is achieved by identifying and retrieving a problem (or a set of problems) most similar to the problem that is to be solved from a case base of previously solved problems (also called cases), and adapting the corresponding solution to construct the solution for the current problem.

To realize a tempo transformation of an audio recording of an input performance, *TempoExpress* needs an XML file containing the melodic description of the recorded audio performance, a MIDI file specifying the score, and the target tempo to which the performance should be transformed (the tempo is specified in the number of beats per minute, or BPM). The result of the tempo transformation is an an XML file containing the modified melodic description, that is used as the basis for synthesis of the transformed performance. For the audio analysis (that generates the XML file containing the melodic description of the input audio performance) and for the audio synthesis, *TempoExpress* relies on an external system for melodic content extraction from audio, developed by Gómez et al. [2003b]. This system performs pitch and onset detection to generate a melodic description of the recorded audio performance, the format of which complies with an extension of the MPEG7 standard for multimedia content description [Gómez et al., 2003a].

We apply the edit-distance [Levenshtein, 1966] in the retrieval step in order to assess the similarity between the cases in the case base (human performed jazz phrases at different tempos) and the input performance whose tempo has to be transformed. To do so, firstly the cases whose performances are all at tempos very different from the source tempo are filtered out. Secondly, the cases with phrases that are melodically similar to the input performance (according to the edit-distance) are retrieved from the case base. The melodic similarity measure we have developed for this is based on abstract representations of the melody [Grachten et al., 2005] and has recently won a contest for symbolic melodic similarity computation (MIREX 2005).

In the reuse step, a solution is generated based on the retrieved cases. In order to increase the utility of the retrieved material, the retrieved phrases are split into smaller segments using a melodic segmentation algorithm [Temperley, 2001]. As a result, it is not necessary for the input phrase and the retrieved phrase to match as a whole. Instead, matching segments can be reused from various retrieved phrases. This leads to the generation of *partial* solutions for the input problem. To obtain the complete solution, we apply *constructive adaptation* [Plaza and Arcos, 2002], a reuse technique that constructs complete solutions by searching the space of partial solutions.

The solution of a tempo-transformation consists in a performance annotation. This performance annotation is a sequence of changes that must be applied to the score in order to render the score expressively. The result of applying these transformations is a sequence of performed notes, the output performance, which can be directly translated to a melodic description at the target tempo, suitable to be used as a directive to synthesize audio for the transformed performance.

To our knowledge, all current performance rendering systems deal with predicting expressive values like timing and dynamics for the notes in the score. Contrastingly, *TempoExpress* not only predicts values for timing and dynamics, but also deals with more extensive forms of musical expressivity, like note insertions, deletions, consolidations, fragmentations, and ornamentations.

3 Results

In this section we describe results of an extensive comparison of *TempoExpress* against *uniform time stretching* (UTS), the standard technique for changing the tempo of audio recordings, in which the temporal aspects (such as note durations and timings) of the recording are scaled by a constant factor proportional to the tempo change.

For a given tempo transformation task, the correct solution is available as a target performance: a performance at the target tempo by a profesional musician, that is known to have appropriate expressive values for that tempo. The results of both tempo transformation approaches are evaluated by comparing them to the target performance. More specifically, let M_H^s be a melodic description of a performance of phrase p by a musician H at the source tempo s, and let M_H^t be a melodic description of a performance of p at the target tempo t by H. Using *TempoExpress* (TE), and UTS, we derive two melodic descriptions for the target tempo from M_H^s, respectively M_{TE}^t, and M_{UTS}^t.

We evaluate both derived descriptions by their similarity to the target description M_H^t. To compute the similarity we use a distance measure that has been modeled after human perceived similarity between musical performances. Ground truth for this was gathered through a web-survey in which human subjects rated the perceived dissimilarity between different performances of the same melodic fragment. The results of the survey were used to optimize the parameters of an edit-distance function for comparing melodic descriptions. The optimized distance function correctly predicts 85% of the survey responses.

In this way, the results of *TempoExpress* and UTS were compared for 6364 tempo-transformation problems, using 64 different melodic segments from 14 different phrases. The results are shown in figure 1. The figure shows the distance of both *TempoExpress* and UTS results to the target performances, as a function of tempo change (measured as the ratio of the target tempo to the source tempo). The lower plots show the significance value for the null hypothesis