Initial Plan: Improving the Realism of a Physically Simulated Musical Instrument

Author: Dave Humphreys
Supervisors: Dr. Kirill Sidorov, Prof. Dave Marshall
Moderator: Prof. Ralph Martin

CM3203: One-semester individual project (40 credits)

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Project Description

One approach to the synthesis of highly realistic musical sounds in virtual instruments is to mathematically describe the physical properties of a real musical instrument and run the simulation of the relevant physical laws on a computer. This approach appears to be far more promising than using sample libraries (as sample-based synthesis is always limited to what samples have been pre-recorded), but is also far more computationally expensive and, implemented naively, does not capture the subtle nuances of sound that are essential for realism.

One problem with physical simulation is tuning of (possibly very many) model parameters, so as to achieve realistic results. This project will involve implementing a (simple) physical model of a bowed string and instrument body - in this instance a Cello. The parameters of the model will be tuned by black-box optimisation so as to match the ground truth sounds of real sampled instruments.

The secondary aim of this project is to leverage the power of graphics processing units (GPUs) for physical modelling of musical instruments.

Both objective metrics and subjective opinion from live trials will be used to guide and evaluate the performance of the system.

Current state of the art

Early analysis published in *On the sensations of Tone as a physiological basis for the Theory of Music* (Helmholtz 1895) identified components of periodic waves producing the perception of tone in relation to musical instruments. In 1979, research put forward in the paper *On the fundamentals of Bowed-String Dynamics* showed the development of a model for bowed string simulation including bow velocity and normal force, and yielded a fast algorithm which would allow the varying of parameters during computation (McIntyre & Woodhouse 1979).

Research continues in an effort to understand and model the intricacies of stringed instruments in real-time, and to produce ever more realistic market products. Julius O. Smith III of the Center for Computer Research in Music and Acoustics, Stanford University, has published a comprehensive overview of instrument synthesis in his paper *Virtual Acoustic Musical Instruments: Review and Update* (Smith 2010). In it, he identifies the classical and digital wave-guide approaches to string modelling, and highlights how non-linear tension modulation (Tolonen 2000) and the application of genetic algorithms to tune wave-guide model parameters (Riionheimo and Välimäki 2003), among other techniques, are helping to increase the realism of string simulation.

At the University of Applied Science in Buchs, Switzerland, a VST virtual violin was developed which used transient non-linear FE model string simulation with impressive results (Schreiner & Geiger). The *Next Generation Sound Synthesis* group at the University of Edinburgh is a European Research Council funded project exploring instrument simulation, in particular using the Finite Time Difference modelling method. They have developed a stringed, bowed instrument implementation based on the theory described in the paper *Physical Modeling of Non-linear Player-String Interactions in Bowed String Sound Synthesis Using Finite Difference Methods* (Desvages & Bilbao 2014) which is also impressively realistic.

Various commercial organisations also develop string simulation based products. The Garritan Personal Orchestra uses a sample-based approach, but with parameters allowing note variations including “automatic changes in attack, timbre, pitch, or other variables” and an “infinite variety of note variations” (Garritan 2005). These applications all demonstrate that not only are physical simulations readily realisable, but there are several reasonable methods from which to choose a basis for such a simulation.

This project will initially investigate the application of physical and sample-based methods, the outcome of this investigation determining the direction chosen for further development.

Project Aims and Objectives

The project will be constructed from two distinct components: a simulation engine, and a parameter optimiser.

Cello simulation engine

The core of the simulation will be a sound source, either a physically modelled string, or a set of pre-recorded samples should this prove a more successful approach. Following trials of both methods, the physical approach will be selected if it is viable and can be shown to produce a high level of realism. Spectrograms will be used to analyse and objectively compare the results of both approaches.

The core output will be passed through a bank of tuned filters which will represent the resonances present in the instrument body, as described in *The Physics of Musical Instruments* (Fletcher & Rossing 1998). Further digital signal processing will be used to add environmental acoustics appropriate to listener placement and the performance environment.

Initially, simple scripting will be used to play the virtual instrument in a versatile manner, and the model engine designed to accept bow normal force, velocity and position, neck finger positions and body composition parameters.

Model optimiser

A separate optimiser module will be developed to compare simulation output to target sounds, and tune model parameters accordingly. The optimiser will accept PCM format audio data, string number and neck position as input, and vary all relevant model parameters to produce simulation output as closely matching the given audio samples as possible in timbre.

Testing and evaluation

Spectrograms and perceptual experiments with humans will then be used to evaluate the system's output, and assess its performance in terms of both realism of output, and attempted replication of actual instrument samples. Real cello recordings will be used for input to the optimiser, and as comparison audio during the subjective experiments.

Development tools

The project will be constructed in Matlab (R2015b), due to its digital signal processing and visualisation capabilities, its native parallel-processing support via GPUs and the speed of multimedia application development possible due to its design and function library. The development machine will consist of an Intel Core(TM)2 Quad Q6600 CPU and Gigabyte GA-965P-DS3 motherboard, with 8Gb DDR2 800MHz system memory and Linux Gentoo OS running kernel version 3.18.9.

Work Plan

Since the project's deliverables involve a degree of experimentation and evaluation, I have decided to follow an Iterative Waterfall approach so that each project component may be developed dynamically, tested and evaluated, and another development cycle initiated should problems occur or new goals become attainable. My plan for this project's progression is as follows:

25/01/16 – 31/01/16: Week 1

- Examine and evaluate project options.
- Discuss and agree on approaches during Supervisor Meeting.
- Develop *Initial Plan* document:
  Draft, proof-read, correct and submit to P.A.T.S.

31/01/16: Initial Plan submission deadline.

01/02/16 – 07/02/16: Week 2

- Obtain/create string-only and full instrument samples for preliminary test use.
- Begin development of preliminary test simulations for string and sample-based implementations.

08/02/16 – 14/02/16: Week 3

- Complete development of preliminary test simulations.
- Evaluate results of initial simulations using objective metrics. **← Milestone 1**
- Present results at Supervisor Meeting; agree *final approach* to simulation core.
- Obtain/create any remaining string-only and full instrument samples needed for final development (recorded within anechoic chamber if required).

15/02/16 – 21/02/16: Week 4

- Develop string simulation core for engine model (physical or sample-based).

22/02/16 – 28/02/16: Week 5

- Develop instrument body simulation, and couple it to string simulation.

29/02/16 – 06/03/16: Week 6

- Present results of current iteration cycle at Supervisor Meeting; confirm development is proceeding correctly and to the standard required.
- Develop ambience model (microphone placement and room simulation using DSP), and couple it to simulation.

07/03/16 – 13/03/16: Week 7

- Test initial simulation engine; evaluate results using spectrogram comparison.
- *DELIVERABLE 1*: Present initial simulation engine at Supervisor Meeting. **← Milestone 2**
- Begin development of parameter optimiser.

14/03/16 – 20/03/16: Week 8

- Complete development of optimiser; test and evaluate results using spectrograms. **← Milestone 3**
- <u>*DELIVERABLE 2*</u>: Present initial parameter optimiser at <u>Supervisor Meeting</u>.

21/03/16 – 27/03/16: Easter recess, week 1

- Integrate system components; verify whether initial requirements were met.
- Perform further development/refinement or final alterations if required.

28/03/16 – 03/04/16: Easter recess, week 2

- Design, test and prepare a suite of perceptual experiments for subjective evaluation of simulation performance.

04/04/16 – 10/04/16: Easter recess, week 3

- Carry out the perceptual experiments with the participation of volunteers.
- Analyse experiment results, and prepare for inclusion in the final report.

11/04/16 – 17/04/16: Week 9

- <u>*DELIVERABLE 3*</u>: Present final, integrated system at <u>Supervisor Meeting</u>. **← Milestone 4**
- Evaluate the system's performance using system metrics and supervisor feedback.
- Begin production of final report:
  Complete *Introduction*, *Background* and *Specification and Design* sections.

18/04/16 – 24/04/16: Week 10

- Continue production of final report:
  Complete *Implementation*, *Results and Evaluation* and *Future Work* sections.

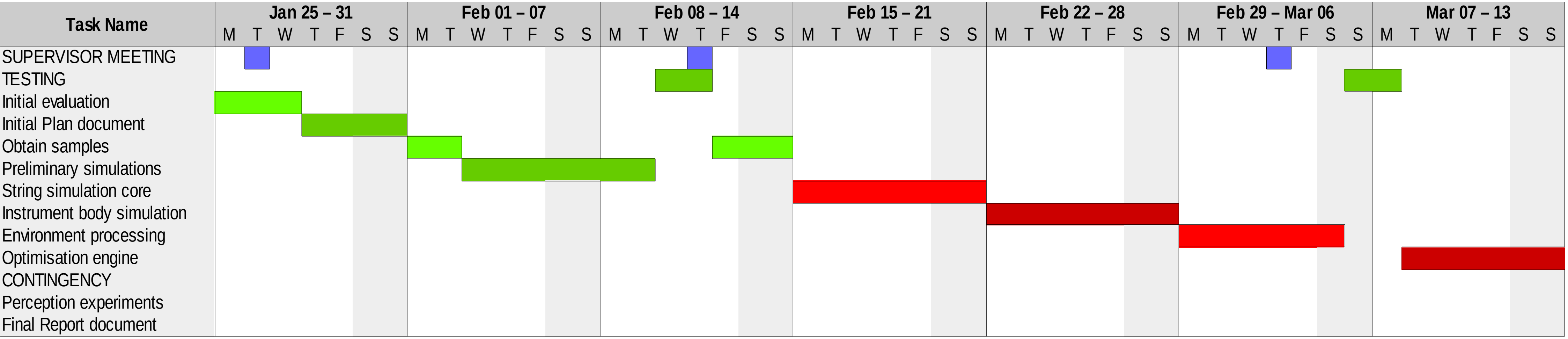
25/04/16 – 01/05/16: Week 11

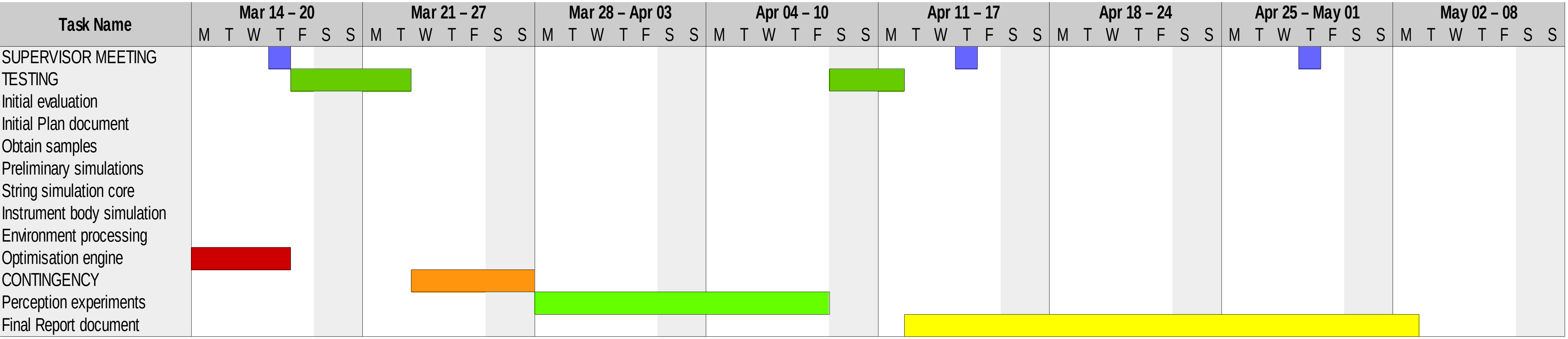
- Complete production of final report:
  Complete *Conclusions* and *Reflection* sections.
- Check and discuss report draft at <u>Supervisor Meeting</u>.
- Proof-read report, verify references and perform final corrections / alterations.

02/05/16 – 08/05/16: Week 12

- <u>*DELIVERABLE 4*</u>: Submit *full* <u>*Final Report*</u> and all <u>*deliverables*</u> (complete Matlab system code, including simulation and optimisation components). **← Milestone 5**
  Aimed submission date: **02/05/16**.
  <u>*06/05/16: Final report submission deadline*</u>.

<u>Gantt Chart: A visual representation of the Work Plan</u> (*25/01/16 – 08/05/16*)





References

Fletcher N.H. & Rossing T.D. 1998. *The Physics of Musical Instruments*, Springer-Verlag, New York.

Garritan G. 2005. *The Garritan Personal Orchestra*. Available at: http://www.oreilly.com/digitalmedia/2005/07/20/garritan.html [Accessed: 27/01/16].

Helmholtz H. 1895. *On the sensations of Tone as a physiological basis for the Theory of Music*, Longmans, Green & co., London, New York.

McIntyre M.E. & Woodhouse J 1979. 'On the fundamentals of Bowed-String Dynamics', *Acustica*, vol. 34, no. 2, pp. 93-108.

Riionheimo J. & Välimäki V. 2003. 'Parameter estimation of a plucked string synthesis model using genetic algorithm with perceptual fitness calculation', *EURASIP Journal on Applied Signal Processing*, vol. 3, pp. 791–805.

Desvages C. & Bilbao S. 2014. *Physical Modeling of Nonlinear Player-String Interactions in Bowed String Sound Synthesis Using Finite Difference Methods*. Available at: http://www.ness-music.eu/wp-content/uploads/2014/05/desvages.pdf [Accessed: 27/01/16].

Schreiner M. & Geiger C., unknown date. VST Virtual Violin. Available at: http://www.michaelschreiner.eu/violin_en.shtml [Accessed: 27/01/16].

Smith III J.O. 2010. *Virtual Acoustic Musical Instruments: Review and Update*, Center for Computer Research in Music and Acoustic, Stanford University, California.

Tolonen T., Välimäki V. & Karjalainen M. 2000. 'Modeling of tension modulation nonlinearity in plucked strings', *IEEE Transactions on Speech and Audio Processing*, vol. SAP-8, pp. 300–310.