

# Toward the Army's Science and Technology Career

Successful First Steps from the Army's Science and Engineering  
Apprenticeship Program for High School Students

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# How I got here – my education

- Twelve years of public-school education
- Currently a rising senior at Chantilly High School, Fairfax County, Virginia
- Applying for colleges!
- Most likely to study electrical engineering, applied physics or mechanical engineering



# How I got here – spring of 2017

- Are unexplainable lab results always due to “instrumentation error?”
- Is that the real lab experience?
- Wanted to know what STEM research is like in a real lab
- AEOP’s Science and Engineering Apprenticeship Program (SEAP)
- Will they take me? I really don’t have much to offer!



# A turning point – summer of 2017

- ARL and my mentor took me!
- Assignment: port Matlab-based shock-and-vibration toolbox into Python
- Mentor taught me about basics of signal processing
- Solid 8 weeks of work wrestling with Python
- At the end of summer, started working on a sound-puzzle that mystified me for more than 8 years



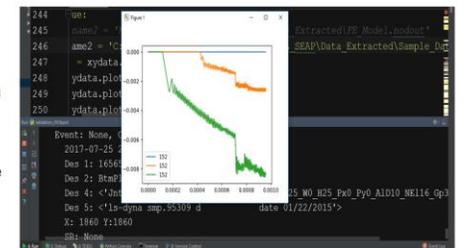
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Mentor: Morris Berman, morris.s.berman.civ@mail.mil

## Abstract

A Matlab-based toolbox for analyzing shock-and-vibration data is partially ported to a Python-based framework using Python 2.7 and highly vectorized SciPy libraries such as NumPy and Matplotlib. Two major tasks were accomplished. First, twenty basic data analysis functions and two more complicated signal-processing functions have been implemented. Second, I accomplished the design and implementation of four "loader" functions to load data stored in four different file formats.

## Background

To improve the analysis of experimental shock-and-vibration data, XYData -- a Matlab-based toolbox -- was developed to achieve three goals: 1) providing a common analysis framework for heterogeneous data sources generated by the shock-and-vibration community, 2) supporting tight coupling of measured data and its metadata, and 3) keeping track of what procedures have been applied to the data for future replication.



| Index | Time       | Element        | Matrix (rows) | sig-x      | sig-y      | sig-z |
|-------|------------|----------------|---------------|------------|------------|-------|
| 26    | 26-        | 1 16 elastic   | 1.8455E+01    | 1.3994E+02 | 0.0000E+00 |       |
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| 2060  | MidRange_I | 95 16 elastic  | 1.8455E+01    | 1.3994E+02 | 0.0000E+00 |       |
| 2070  | MidRange_I | 96 16 elastic  | 1.8455E+01    | 1.3994E+02 | 0.0000E+00 |       |
| 2080  | MidRange_I | 97 16 elastic  | 1.8455E+01    | 1.3994E+02 | 0.0000E+00 |       |
| 2090  | MidRange_I | 98 16 elastic  | 1.8455E+01    | 1.3994E+02 | 0.0000E+00 |       |
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| 2110  | MidRange_I | 100 16 elastic | 1.8455E+01    | 1.3994E+02 | 0.0000E+00 |       |

```
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2017-07-26 20:55:33.779000
Des 1: 26
Des 2: BottomRight_E
Des 4: '<Int_TopMoves_Int_Pkt_DepCtl_LR26000_S25_W0_H25_Fx0_Py0_AID10_N6116_Qp350
Des 5: '<1s-dyna_smp.95309 d date 01/22/2015>'
X: 10002 Y:10002
SR: None
Event: None, Channel: 26
2017-07-25 20:55:33.779000
Des 1: 26
Des 2: BottomRight_E
Des 4: '<Int_TopMoves_Int_Pkt_DepCtl_LR26000_S25_W0_H25_Fx0_Py0_AID10_N6116_Qp350
Des 5: '<1s-dyna_smp.95309 d date 01/22/2015>'
X: 10002 Y:10002
SR: None
```

## Toolbox Development and Usage

In porting from Matlab to Python, I began with implementing basic data manipulation and analysis functions. Throughout the porting process, I had to rely heavily on the NumPy, Matplotlib and SciPy libraries which are highly vectorized and can perform computations on large data efficiently. Furthermore, I have figured out how to make a "deepcopy" of an XYData object which can serve as the pristine version of the original data while the loaded data undergo a variety of transformations.

```
loadnodout() for file in file_list if file.endswith('.for i in range(
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```

## Discussion/Path Forward

With the short eight weeks of my internship, I realize that there will be some aspects of the toolbox that I might not be able to implement, such as the GUI. In addition to the four implemented loader functions, the toolbox would benefit from the addition of more loader functions as well as more signal-processing capabilities. I would like to thank my mentor, Mr. Berman, for the instruction that he has provided in helping me with this project.

# Many pleasant surprises – my junior year

- Won grand prize at Northern VA Science Fair → Intel ISEF finalist
- Won 1<sup>st</sup> place at Virginia State Junior Science and Humanities Symposium (JSHS)
- Won 2<sup>nd</sup> place (physics category) at National JSHS
- Army S & T Symposium invited me to share my journey of science exploration (education outreach)

## The Effect of Spectral Content on Acoustic and Synthesized Timbre

Justin Wang  
Chantilly High School

### Abstract

- What contributes to the perceived differences between acoustic violins and synthesizers? Can we remove the unrealistic vibratos from synthesizers?
- 3-D visualization of the spectral content and ANOVA tests were performed – the inharmonic content contributes most significantly to the perceived differences in timbre
- To remove vibrato, modified spectral components are subsequently converted back to the time-domain audio signals. Listening tests and visualization provide further evidence of successful removal

### Methods / Materials

**Data Collection**  
Record tones from two violins and two synthesizers as WAV signals

**Spectral Analysis**  
Perform spectral content analysis and visualization of each scale or note

**Tools**  
Python's SciPy modules (NumPy, Matplotlib, Stat, and Signal)

### Results

**Visualization of Spectral Content**

**ANOVA Test Results**

| Scale | One-way ANOVA      | IQ-1 Among v1, v2, s1, s2 | IQ-2 Between V and S | IQ-3 Between v1 and v2 | IQ-4 Between s1 and s2 |
|-------|--------------------|---------------------------|----------------------|------------------------|------------------------|
| C4    | F-statistic: 211   | 38.413                    | 114                  | 115.478                | 327                    |
|       | p-value: 888       | 789                       | 7                    | 291                    | 569                    |
| C5    | F-statistic: 2318  | 29.524                    | 6.262                | 78.403                 | 238                    |
|       | p-value: 138       | 89                        | 638                  | 242                    | 884                    |
| C6    | F-statistic: 4.676 | 17.628                    | 2.972                | 53.070                 | 9.911                  |
|       | p-value: 608       | 130                       | 7                    | 301                    | 383                    |

### Conclusions

**Goal 1: Understand spectral content's impact on timbre**

- Visualization of the spectral content of harmonics and inharmonics demonstrates differences exist in their timbre content
- Logical series of four ANOVA tests provided evidence that the inharmonic content contributes the most in terms of the timbral differences between acoustic violins and synthesizers
- Experimental results support musical literature concerning synthesizers which could not easily replicate the timbre of a string instrument due to its inharmonics (Berg and Stork). However, the results disagree with beliefs that timbral differences arise from harmonic content (Smith)

**Goal 2: Remove synthesizer's vibrato to enhance timbre**

- Best results obtained utilized a simple yet quite elegant method by adjusting the spectral amplitudes near the harmonics of the tone
- Modified spectral components were subsequently converted back to the time-domain WAV audio signals
- Listening tests of the modified WAV audio and visualization of its corresponding spectrogram provided further evidence of successful removal of the vibrato

### Introduction / Background

- Learned signal processing for shock and vibration – DoD internship 2017
- Played violin and piano since 4<sup>th</sup> grade
- Synthesized string tones are most unrealistic
- Existing literature presents conflicting information regarding what attributes to our perceptual differences in timbre quality
- Is it harmonic or inharmonic content?
- Hypothesis: There are differences in how spectral energies are distributed in instruments' "timbral content"
- 3 scales and 8 – 12 harmonics

### Goals

- **Goal 1:** To obtain a complete understanding of what contributes to the unrealistic perception of string tones generated by synthesizers, through detailed spectral content analyses at macro and micro levels
- **Goal 2:** To design and implement an algorithm to remove a tone's vibrato – a rapid, pulsating change of pitch but rather mechanical and unrealistic – generated by synthesizers

### Steps for Vibrato Removal

- #1: Record the tone with vibrato
- #2: Transform time-domain  $W$  to frequency-domain  $F$
- #3: Find local maxima of  $F$  using neighborhood size  $N$
- #4: Sharpen the amplitude of local maxima
- #5: Remove the local maxima
- #6: Loop Steps 3 – 5  $n$  times to dull the amplitudes
- #7: Generate a new  $W$  based on modified spectrum
- #8: Listen to the new  $W$
- #9: Visualize the new spectrum and spectrogram

### Future Work

- Continue to develop the tool for young violinists to analyze richness of spectral content before buying their first instruments
- Develop features to examine the quality of sounds attributed to acoustic violins and bows by isolating them

### References

Berg, R. E., & Stork, D. G. (2005). *The Physics of Sound*.

Olyphant, T. E. (2007). *Python for Scientific Computing*.

Downey, A. (2014). *ThinkDSP: Digital Signal Processing in Python*.

Smith, S. W. (1997-2011). *The Scientist and Engineer's Guide to Digital Signal Processing*.



# Back to ARL again – summer of 2018

- Concerned about congressional budget; glad to be back
- Worked on a project developing a self-cooling chip
- Used last summer's shock-and-vibration toolbox efforts to simplify data handling this summer
- My contribution: convergence study of heat transfer from temporal and spatial perspectives
- Have learned tremendously, again



Convergence Study of ParaPower



**Abstract**

Numerical methods are commonly used to solve problems in heat transfer. Commercially available numerical solvers emphasize high-fidelity, high-accuracy models, with computational resources and user efficiency being a secondary consideration. At ARL, we have developed a numerical solver known as ParaPower, which emphasizes computational efficiency and user-efficiency across a range of accuracy. The goal of the project is to quantify the trade-offs between the methods, so that users will be able to make informed decisions as to which model – high fidelity with low efficiency, or lower accuracy with higher efficiency – is more appropriate for a given application.

We tackle this problem by performing a convergence study with the two parameters – spatial and temporal discretization – that are most influential in determining the accuracy of the numerical solution. As of this writing, the temporal convergence study has been implemented, which shows first-order convergence. We continue to understand the spatial convergence behavior to determine an acceptable mesh-density and accuracy level. Both parameters play crucial roles in determining an appropriate level of trade-offs in accuracy and efficiency between high-fidelity models such as ANSYS and more efficient models such as ParaPower.

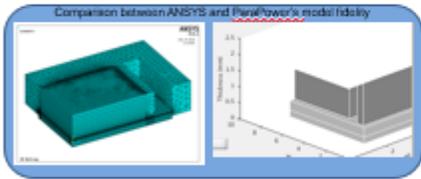
**Background**

- Current thermal designs utilize steady-state thermal dissipation
  - Heavy overdesign, large size and weight, low power density
- Goal: Implement a steady-state and transient solution
- Optimize a transient thermal solution for different layouts
- ParaPower:
  - Highly efficient numerical solver – coarser meshes
  - Less accurate than high-fidelity models – ANSYS – denser meshes
  - We want to quantitatively determine ParaPower's accuracy – qualitatively it converges
  - Convergence studies – a "close-enough" solution

**Results**

- ParaPower convergence behavior:
  - Temporal discretization shows first-order convergence
  - We use  $u_0$  to find  $\alpha$ , the order of convergence

**Comparison between ANSYS and ParaPower's model fidelity**



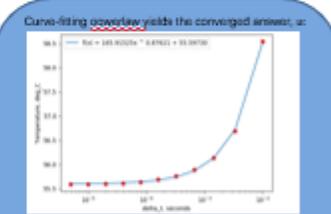
**Temporal and Spatial discretization:**

- $p$  = Order of Convergence
- $u$  = converged answer; exact value of numerical approximation
- $u_h$  = the numerical approximation at some discretization  $h$ 
  - $h$  can be time step or mesh density

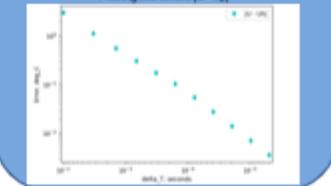
$$2^p + O(h) \quad \alpha^{-p} + O(h)$$

$$\log_2 \frac{\hat{u}_h - \hat{u}_{h/2}}{\hat{u}_{h/2} - \hat{u}_{h/4}}$$

**Curve-fitting exercise yields the converged answer,  $u_0$**



**Plotting the errors  $|u - u_h|$**



**Conclusion and Path Forward**

- For temporal discretization, ParaPower converges with first order convergence
- Spatial discretization convergence study is ongoing
- Order of convergence can be used to compare the accuracy/efficiency of other solvers
- Order of convergence can be used to optimize ParaPower models and reach a desired accuracy level
- Recognize when "diminishing returns" begin and accuracy is "good enough"

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**Mentor:** Morris Berman  
 morris.s.berman.civ@mail.mil

# Reflection – 16 weeks of internship at ARL

- No better way to spend the two summers
  - Sense of responsibility
  - Use of public transportation!
  - Improve my technical skills
  - Meet other like-minded high schoolers, undergraduates, and graduate students
  - Clear my doubt regarding “instrumentation error”
  - **Meaningfully contributed to my mentor’s project**
- Solidify my selection of an engineering career
  - Engineering physics or electrical engineering



# Reflection – 16 weeks of internship at ARL

- Remove any doubt whether math and physics are essential
  - See how they are used in a real lab
  - Use of instrumentation
  - Math modeling & model comparison
  - Heat transfer and phase change materials
  - Data processing and programming
  - Use of HPC systems – HPCMP ORS
- I really like the staff at ARL
  - They treated me like I am one of them
  - Hope to come back to intern for four more summers while in college



# Reflection – DoD-sponsored JSHS competitions



- Competition format encourages communication
  - Written & oral
  - Judges are college professors or experts in the judging field
- Competition categories
  - Environmental, biomedical, life, medicine, engineering, math & computer, physics, chemistry
- Great to see so many like-minded future scientists
- Speakers and panelists for the National JSHS were fantastic
- Toured many DoD facilities



# Where can I go from here – back to school

- None of the above could be possible without
  - AEOP: SEAP & JSHS & **ARL**
  - Time and energy my mentor spent on me
  - ARL colleagues' open arms & great projects
  - Countless people from ARL and AEOP
- 8-week is really too short
  - Getting momentum to contribute around week 6
  - Almost time to wrap up!
  - But I have not finished the assignment yet
  - May I stay a bit longer?



# Extending beyond an 8-week apprenticeship

- Recalled past conversations with students who participated in science competitions
  - I explored a very simple idea of my own
  - Many other students continue investigations from larger projects originated from government or university research labs
- Is it possible to extend duration of the internship beyond summer?
  - Benefit of the mentor's project and the apprentice
  - Guest researcher?



# Parting words

- SEAP and JSHS opened my eyes to the world of STEM lab career
- ARL has changed my future prospect
- Grateful for my ARL mentor-and-colleagues' guidance and support
- Hope to participate in 2019 DoD-JSHS competition
- Look forward to coming back to ARL for college internships:
  - DoD's SMART Scholarship for Service Program
  - AEOP's URAP
  - AEOP's CQL
- I plan to be back to present a technical topic at a future Army S & T Symposium & Showcase!

