Granola is software for increasing the energy efficiency of laptop and desktop computers. Granola accomplishes this by decreasing the capability of the system while it is not fully utilized and increasing it to maximum when necessary. By matching capability to demand, Granola helps to realize energy-proportional computing without the need for application-awareness, turning computers off, or new hardware.

Since the release of the Granola family of software, there have been some questions about the applicability of this software to a number of specific scenarios. In this paper, we present some answers to these questions across a range of applications, ranging from document editing and productivity software, such as Microsoft Office, to games and entertainment software. As you'll see, Granola performs exactly as it should: saving energy when the system is under-utilized, while providing the full power of the system when it is necessary.

Experimental Setup.

A careful eye to experimental setup is important in making experiments repeatable. There are numerous elements in a running computer system that can make the results of a power benchmark unpredictable. From the accuracy of the metering hardware, to the nonlinearity introduced by computer components like batteries and monitors, to the running background processes on a system – by eliminating and controlling as many elements as possible, one can approach 100% repeatable experiments.

Hardware environment. For the experiments, the hardware was chosen to be representative of what would be available to an average user. The machine used for testing was a Sony VAIO VGN-NR498E laptop. This laptop features an Intel Core 2 Duo CPU, 3GB of RAM, and a 320GB hard drive. For the experiments in this whitepaper, the laptop battery was removed so that the charging of the battery would not affect the measured power consumption. The laptop was also plugged into an external screen, USB keyboard, and USB mouse. The laptop was then used closed to further isolate the power consumption of the laptop. Figure 1 contains a diagram of the hardware setup.

The power consumption of the laptop was measured by a Watts up? PRO power meter. These meters represent a class of relatively high-accuracy consumer-grade meters, frequently used for measure the power consumption around the home. The accuracy of these meters is +- 1.5%. The Watts up? PRO also includes the ability to output the data it collects via USB, allowing the user to log the data on their computer and interact with the results. The laptop in our experiments was attached to the meter in this way, and we gathered the results using the software setup described below.

Software environment. The laptop used for the experiments below runs the Windows 7 64-bit

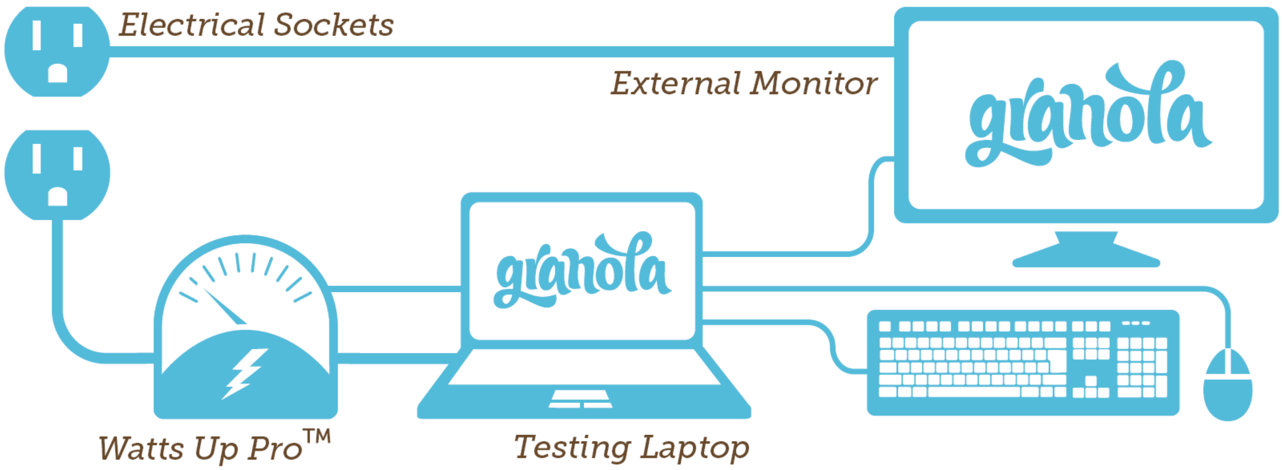

Figure 1. Experimental hardware setup. The laptop is connected to the Watts up? PRO meter, while the external monitor is attached directly to the power outlet.

Professional operating system. A piece of software is needed to extract the meter data from the USB interface. For the experiments described below, the laptop was running the WattsUpMon software [http://mvolo.com/files/WattsUpMon.zip]. This software reads from the power meter and updates several Windows performance counters with the data from the meter, allowing the user to script queries.

A VBScript script was used to query the power consumption via the performance counters exported by WattsUpMon. A Bash script then made calls the VBS script at regular intervals while executing a workflow to generate the power trace for the workload in question. The Cygwin command-line tool was used to provide an environment for creating and running Bash scripts.

The JitBit Macro Recorder [http://www.jitbit.com/macrorecorder.aspx] was used to drive the productivity tests. This software will record all of the keyboard and mouse events processed by Windows, allowing a user to replay an arbitrary sequence of events with the system responding exactly as it would have had the user been interactively using the keyboard and mouse. By replaying the macros recorded by JitBit, we can create repeatable user-interaction workflows.

In all of the experiments, we are using Granola for Microsoft Windows.

Overview of the experiments.

Four workloads were chosen as representative user workloads for laptops and desktops. These workloads cover several common tasks for this class of systems.

Document editing. Document editing is a common task for users of laptop and desktop computers. In order to test the performance of Granola during such a workflow, a user was recorded using the JitBit software while editing and interacting with a multimedia document. Specifically, the user worked in Microsoft Office Word 2007 to edit the text, figures, footnotes, and other elements of a 50 page document. This workflow included periods of the computer at almost idle – for example, while the user was reading a section of the document – interspersed with periods of high levels of disk, memory, and CPU activity, such as when the user was editing a large embedded image. After the user actions were recorded, they were played back several times using the JitBit software both with and without Granola, recording the power consumption traces using the software described earlier. The entire workflow was 10 minutes, 30 seconds long.

Productivity. Another common task is using productivity software, such as Microsoft Excel, to manipulate large amounts of data, generate graphs, and draw conclusions. Similarly to the document editing workload, to test the performance of Granola during a productivity workflow, a user was recorded with the JitBit software interacting with a large spreadsheet, computing new columns of data, and creating charts and graphs. Specifically, the user used Microsoft Office Excel 2007 to import and edit the data from two external data files. After import, the spreadsheet contained approximately 120,000 cells of data. The user added four new columns, each of which was calculated from the imported data using built-in functions like AVERAGE() and MAX(). The user then created two scatter plots from the resulting data. The scatter plots were then edited for style and content, and moved around the spreadsheet. After recording, the actions were played back using the JitBit software both with and without Granola, recording the power consumption traces using the software described earlier. The entire workflow was 8 minutes, 35 seconds.

Gaming. While document editing and productivity software are frequently used, many people spend much or all of their time using their computer for entertainment. Many desktop systems are built exclusively to run high-end graphical video games which require the full capabilities of the system in order to play smoothly. To test the performance of Granola in situations such as this, where the system must run to the fullest of its capabilities, a demo of a graphical video game was recorded and played back. Specifically, a time-demo of the Half-Life 2 game was recorded and replayed and measured for power consumption and performance. Half-Life 2 allows for the direct recording of a time-demo (similar to a JitBit macro) from within the game. The time-demo can then be replayed, re-creating the actions of the player in the game. The user was recorded playing part of the level “d1_canals_09” (and not very well!). The time-demo was then played back as fast as the computer can draw the actions. The frame rate of the playback was recorded alongside the power consumption both with and without Granola. The entire length of the time-demo was 13 minutes, 4 seconds.

Entertainment. Another common recreational task, especially on laptops, is watching DVDs. Unlike the graphical game, watching a DVD is long period of low-intensity utilization, with occasional spikes as the DVD buffers more data into memory. To test the savings under this scenario, a DVD was played back using the VLC media player both with and without Granola, recording the power consumption traces using the software described earlier. The entire length of the playback was 90 minutes, 31 seconds.

Listing 1. Directions for running a power benchmark experiment.

To get the base power consumption without Granola for a given test:

1) Set the operating system power settings to the “High” profile in the Power Options.
2) Start the WattsUpMon software.
3) Start the performance counter logging script.
4) Start the test workload.
5) When the workload finishes, stop the performance counter script.

To get the power consumption with Granola for a given test:

1) Set the operating system power settings to the “High” profile in the Power Options.
2) Start the WattsUpMon software.
3) Start the performance counter logging script.
4) Start Granola.
5) Start the test workload.
6) When the workload finishes, stop the performance counter script.

Workload	Average power without Granola (Watts)	Average power with Granola (Watts)	Savings (percent)
Document editing (Microsoft Word)	21.95	18.90	13.88%
Productivity (Microsoft Excel)	21.06	17.86	15.22%
Gaming (Half-Life 2)	41.38	40.36	2.46%
Entertainment (VLC Media Player)	30.97	25.29	18.32%

Table 1. Average power and savings data from all four workloads. For high-utilization workloads, there is proportionally less energy savings.

Experimental Methodology.

For each test workload described above, the workloads were run both with and without Granola a number of times. The power consumption was logged every half a second for the entire duration of the workload, using the VBScript script described above. The results were imported into Microsoft Excel for analysis and graphing. Listing 1 contains the in-depth description of the technique for collecting the numbers with and without Granola.

After collecting the numbers with and without Granola, import the sequences into a spreadsheet program. By graphing the two sequences (with and without Granola) on the same graph, one can align the two graphs and visualize the savings that Granola offers. The figures in the results section show this type of comparison. By summing the power consumption numbers with and without Granola for a given workload, and comparing them, you can get the percentage savings. The table in the results section shows this sort of comparison.

Results.

The overview of the results of the experiments is shown in Table 1. For the document editing and productivity workloads, where a large amount of time is spent at lower utilization while the user reads

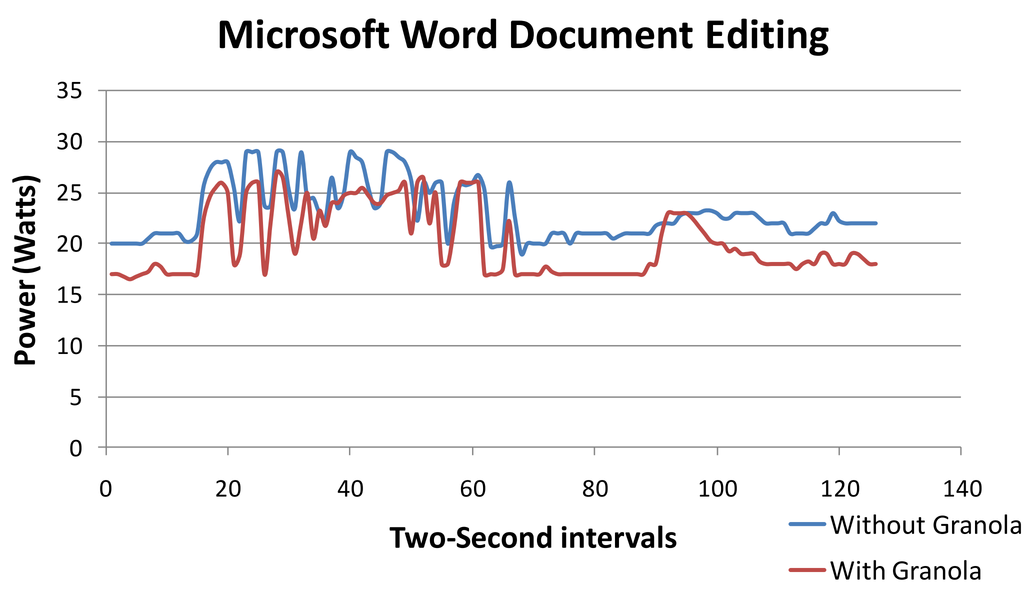

Figure 2. Power trace for the document editing workload, with and without Granola.

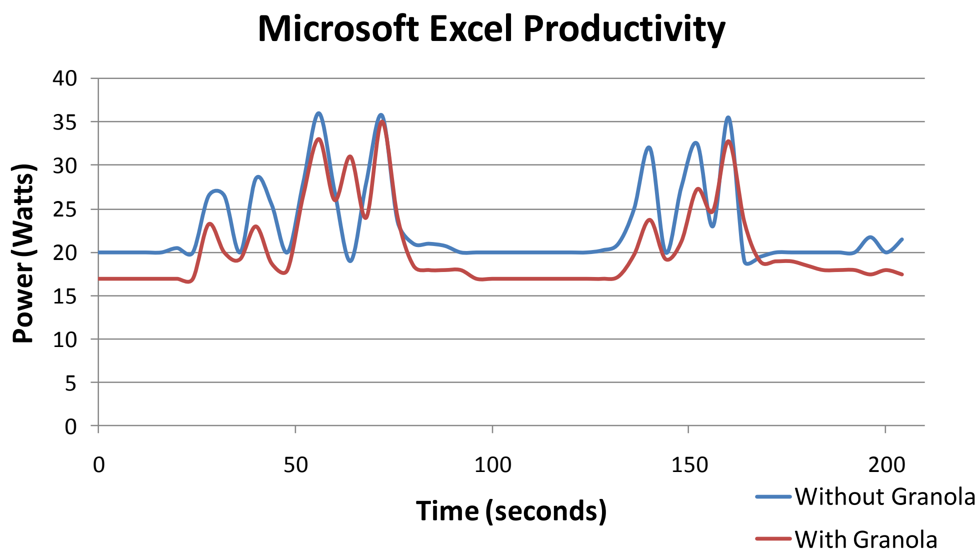

Figure 3. Power trace for the productivity workload, with and without Granola.

texts or looks at data, the savings numbers are significant: almost 14% for the document editing and over 15% for the productivity. The best savings numbers, though, come from the DVD playback workload with a savings of 18.32%.

Document editing. Figure 2 shows the like-to-like comparison of the power consumption for the Microsoft Word 2007 document editing workload with and without Granola. The values have been smoothed by averaging consecutive samples in order to smooth the graph a bit. The figure shows that for most of the workload, Granola reduces the average power consumption of the laptop significantly. In some sections of the graph, such as around the 60 sample mark, the power consumption with and without Granola is very similar. During these periods, Granola has determined that the higher power states are required to complete some action with no performance loss.

Productivity. Figure 3 shows the comparison of the power consumption for the Microsoft Excel 2007 productivity workload with and without Granola. Again, the samples were smoothed. As with the document editing workload, there are periods in which Granola saves significant energy and periods in

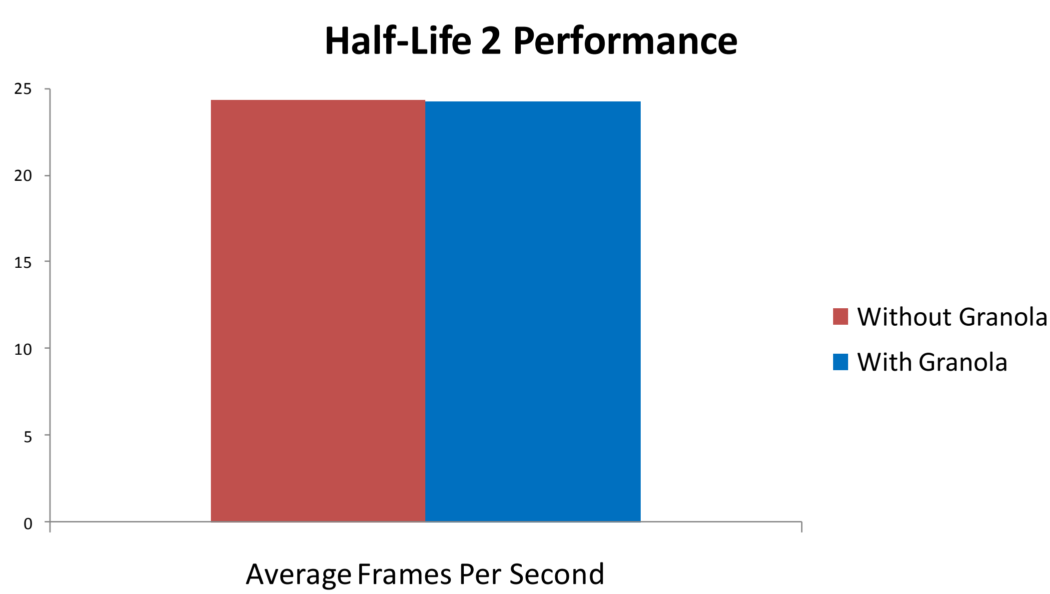

Figure 4. Performance (FPS) comparison of Half-Life 2 gaming workload with and without Granola.

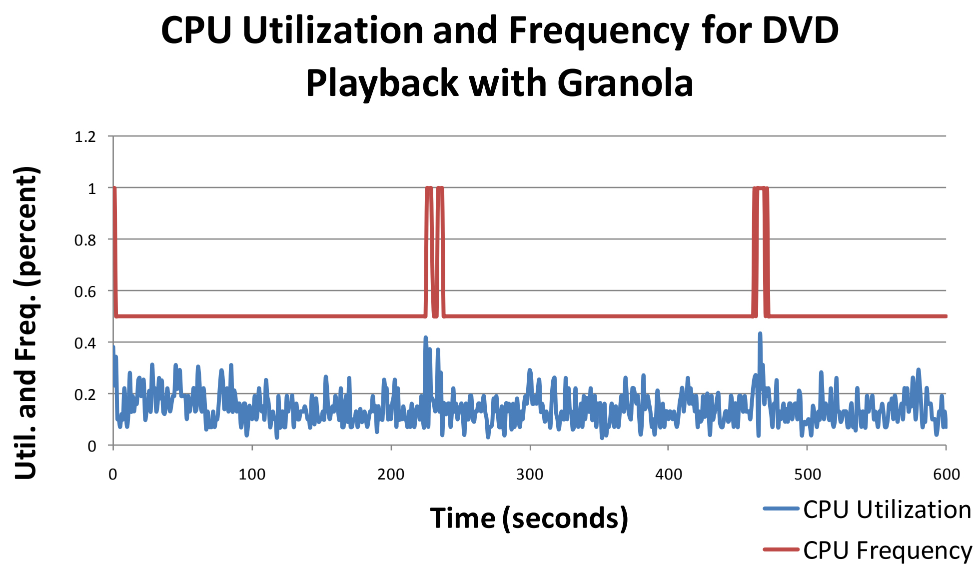

Figure 5. Trace of CPU utilization and frequency with Granola for the DVD playback workload.

which Granola maintains performance by increasing the power state to match that of the full-speed run.

Gaming. Figure 4 shows the performance data from the Half-Life 2 gaming workload with and without Granola. As mentioned earlier, the correct behavior for Granola in the context of this workload is to put the machine in the highest power state in order to ensure no performance loss. As the figure shows, Granola does just that.

Entertainment. As shown in Table 1, the overall power consumption for the DVD playback is higher than for the document editing and productivity workloads. This is due to the fact that the DVD drive itself is active during the playback. Figure 5 shows the CPU utilization and the frequency as set by Granola during a 10 minute window of the playback. As the graph shows, during periods of higher utilization, such as when the computer is buffering the next section of video, there is a corresponding spike in CPU utilization. Granola responds during these periods by increasing the CPU frequency as appropriate. Generally though, Granola reduces the power consumption during the periods of low utilization.

Conclusion.

Granola improves the energy efficiency of laptops and desktops by matching computing capacity to computing demand. Over a set of workloads including document editing, productivity, gaming, and entertainment, Granola saves a significant amount of energy while maintaining performance when needed. By installing and running Granola, users can improve the energy efficiency of their computer systems across a range of workloads without affecting their productivity and entertainment.