D3D-Porteus – A Software Kit For RepRap Assembly Workshops

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Abstract

Contents

1   Introduction

Americans workers produced goods and services twice as quickly in 2014 as in 1970 according to OECD labour productivity statistics[1] plotted in Figure 1. While half of current productivity took 200 000 years (all of human history) to realize, the other half was added in only ca 40 years. Something very special has happened, and the unusualness of the situation has inspired the following work.

Productivity is closely related to available tools and machinery, and a large part of the recent increase is attributed to the advent of computers and the Internet.(source: Dale Jorgenson & Kevin Stiroh, Kevin Stiroh, Dale Jorgenson & 2 coauthors) However, these machines have been criticized for being hard to use, error prone and complicated. In 1987, when organizations were still only beginning to make use of computers, economist Bob Solow noted

> "You can see the computer age everywhere but in the productivity statistics."[2]

What he had observed turned out to be a learning pause followed by rapid productivity growth, as seen in Figure 1. Since then, big organizations have learned and reorganized themselves to dramatically increase efficiency using computers.(source Brynjolfsson & Hitt) What we see in Figure 1 is that median people are still not using modern machines effectively for personal economical benefit. To get median people's incomes over the productivity lag of 1987 we expect that they must do what the big organizations did, namely learn computer based production and reorganize to realize its potential benefits. As engineers there are things we can do to ease their journey.

1.1   Copability and Structural Virality

Simple and small scale machines are preferred as starting points for learning.(source) However, since small scale often means less efficient we must search for other potential economical advantages with them. One such advantage might be the possibility to copy the machine oneself and even distribute such copies. Under the slogan "wealth without money"[6] the RepRap Project proved the feasability of user distribution by demonstraing and publishing the design of a 3D printer that was practical for many and legal for anyone to make copies of[7, 8]. We refer to the practical ease and legal possibility of making physical copies from a machine design as the design's *copyability*. It
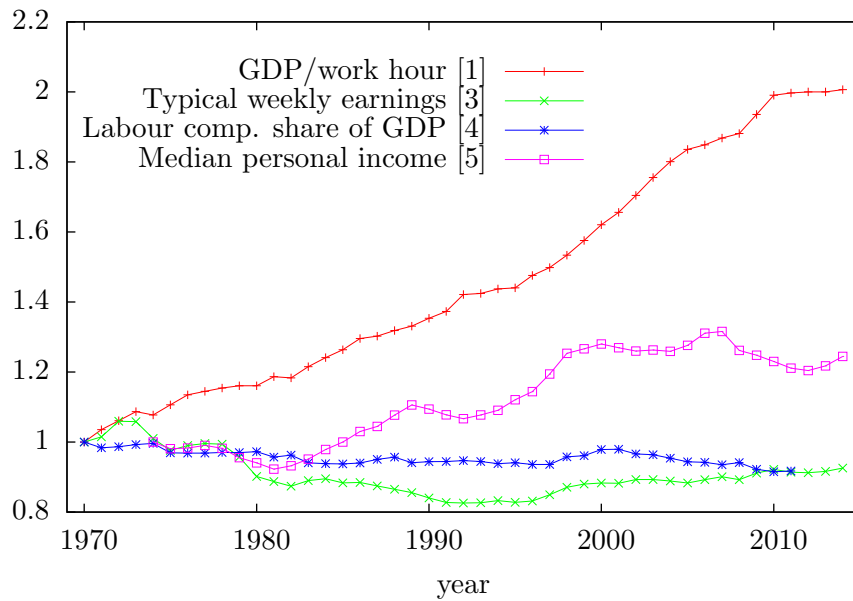
Figure 1: This plot shows that labour productivity (GDP/work hour) more than doubled in the USA between 2014 and 1970. It also shows a decoupling from real income growth who have increased ca 8.5 ± 16 %. Labour compensation's share of the total GDP is shrinking because other groups' incomes are growing faster. "Typical earning" refers to that of production and non-supervisory workers in private nonagricultural industries. Prices are constant in relevant data sets. Sources: [1], [3], [4] and [5].

describes the ease at which users can become suppliers.[1]

A high copyability gives a machine design two important characteristics. First, every part of the copying process that requires human intervention gives that human a level of control. It implies a possibility to study the machine and over time learn how to use it for one's own purposes. Second, it enables the machines to spread with a high *structural virality*, meaning that a tree structure describing their spread among people can have a high mean path length[9].

Seeing machinery as goods, there are two general strategies for production and distribution. Either concentrate production and distribute ready built machines from a central point, or aim for high structural virality to spread out machine production itself. These two strategies are modelled in Figure 2. With an aim to benefit median people, and being enabled by high copyability, it is natural to test the second strategy. A high structural virality would spread out the benefits from producing and distributing machinery by default without requiring additional goods distribution or economical redistribution. The system also gets resilient since dependencies on single suppliers are avoided.

To preserve structural virality one must forward complete sets of abilities, that is tools and knowledge, to enable futher independent distribution. Everything that is supposed to flow from person to person must be copyable.

1.2 RepRap

RepRap 3D printers were invented during 2005 – 2008[7, 8]. Structural virality of development was high enough that the originators no longer were in control of development by October 2010[8]. Development has since diffused further but new knowledge still gets captured in the forum threads, blogs and wiki pages of the online RepRap community. The copyability of RepRap 3D printers comes from their free licencing, low price, widely available parts and design files, helpful Internet community and the ability to manufacture a large fraction of their own parts[7]. As of spring 2016, many RepRap 3D printer designs as well as copy-limited 3D printer designs compete on global commercial markets. Unlike do-it-yourself machines in earlier industrial history, like home-made cars and fridges, the RepRap 3D printers have not been completely outcompeted or displaced. Instead, RepRap designs hold a stable 7% market share.(source) The originator of the RepRap Project, Adrian Bowyer, has made the following competition related comment

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[1]A measurment of copyability would be subjective, and the term is not in wide spread use. We introduce it here to help an intuitive understanding.
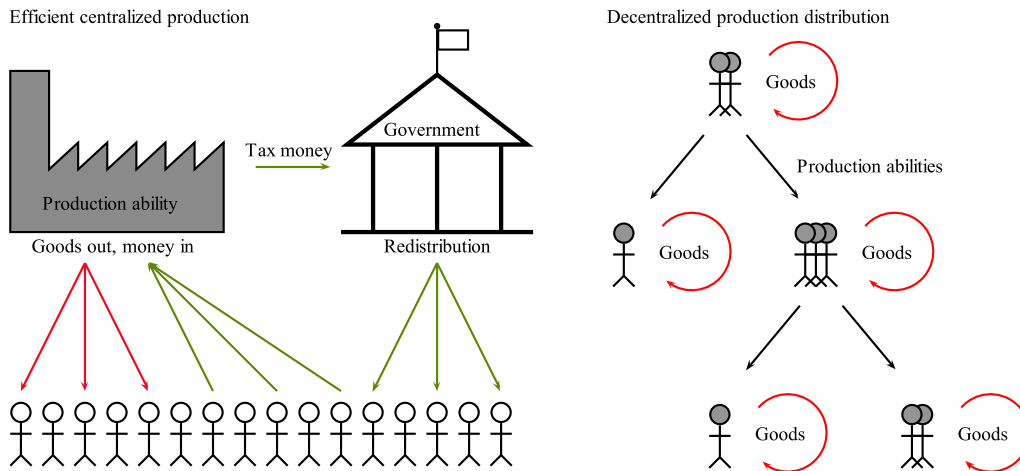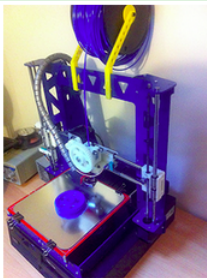
Figure 2: Stick figure explanations of two different models of production and distribution. The left one shows distribution of centrally produced goods coupled with a redistribution cycle of money. In the right model, groups of small scale producers are the main actors and production abilities are distributed, flowing along the black arrows.

> "I don't really think that maintaining the position [in the DIY 3D Printer and Maker community] is a problem. After all, if every non-replicating 3D printer makes just one RepRap at some point in its life, you can see what that does to population dynamics."[10]

Despite their copyability and geographically diffused development, it is likely that both RepRap hardware and RepRap knowledge have spread with relatively low structural virality. This has been found to be the case for things as easily copyable as popular tweets and re-tweets[9]. Central RepRap sources like blogs and hardware suppliers are easily spotted on the Internet by simple web search. These are one-to-many sources of knowledge and hardware that keep structural virality down. On the other hand, the existence of web-stores that supply Prusa i3 machines that have had their design remixed in two separate stages over just 1 year (Prusa i3 announced May 2012[11], P3Steel announced April 2013[12], see Figure 3) suggests a structural virality that is nonetheless higher than what we are used to within manufacturing.

Further increasing structural virality of RepRap spread would require increasing the *ability flow*, drawn as black arrows between the small groups in Figure 2. It would require that those who have production abilities actively share their abilities so the productivity itself can spread without restrictions. In terms of enterprises it would require that production enterprises create and

Figure 3: Screenshot from `reprap.org/wiki` showing someone designed a remix of a remix of the Prusa i3 RepRap design. This particular design has a reduced copyability compared to Bowyer and Prusa's RepRap designs due to its non-commercial licence. It is easily confirmed by quick web search that some users have managed to become suppliers.

sell unrestricted copies of themselves. This would feel new to many and the copying and sharing might even seem unfeasible from a market competition perspective. We therefore make the following short comment on feasibility of productivity sharing.

Erik de Bruijn documented both the existence and efficiency of sharing by FLOSS methodologies within production of physical goods in his examination of the RepRap community in 2010[13]. The motivation behind such sharing is diverse and is described by [14] and (von Hippe et al 2010). (Ryan & Deci 2000) have formulated and provided empirical support for modelling feelings of autonomy, competence and connectedness as basic human needs. We assume that these needs can motivate the sharing of production ability if people find the sharing event itself enjoyable and practically feasible.

1.3 RepRap Assembly Workshops

Strong ability flows and a willingness to share production machinery have also been demonstrated through RepRap assembly workshops. These are events where participants meet up in person to get guided through series of assembly steps, and get to bring partly self-assembled RepRaps with them home. They realize advantages of simple and small scale machines, namely that they are affordable and relatively easy to teach. We have found no reports that RepRap assembly workshops have reached high structural virality yet but there is no doubt that they occur. One way to reach the general public in a structurally viral way would be by making RepRap assembly workshops more copyable themselves. This would include making tools and knowledge more copyable and thus make the workshop experience more enjoyable and practically feasible.

A minor contribution of this paper is the following description of Josef Prusa's work. It is not surprising that it is the Prusa design that is mentioned as the base of remixing in Figure 3. In 2010 – 2013 he hosted a series of RepRap assembly workshops across Europe, funding his airplane tickets by manufacturing and pre-selling RepRap parts to future participants. The RepRap design named after him that he used and co-developed was easy to assemble compared to other RepRap designs at the time. It made hosting assembly workshops as short as two days viable, which helped their popularity. Hundreds of people were tutored, and the community developed a whole family tree of RepRap Prusa versions and remixed designs. As of 2016, machines based on this design family have been copied well over 85 000 times (see Appendix A for sources and method behind this estimation) and are still very popular.

A second minor contribution of this paper is the following summary of

the state of RepRap assembly workshops in Europe and the USA by spring 2016. Copyability properties of Prusa's workshops themselves have not been widely discussed but there have been hosted series of assembly workshops by active members of makerspaces, fablabs and universities both before and after Prusa's travelling workshops. Many hosts now prefer teaching usage instead of assembly. This may be because assembly workshops get too long, or because prices get too high compared to mass-produced kits ordered directly off the Internet. Kits are the largest running expense for an assembly workshop host, many prefer to teach their own designs to make teaching easier. Cheap and efficient kit production is hard and may require surprising work and expenses for hosts.

The MOST lab at Michigan State University have mentioned difficulties with training instructors and the large range of possible assembly errors as additional problems. Among hosts they are an exception, currently hosting four day assembly workshops free of charge for students. They have also set up a kit supplier of their own 3D printer design.

1.4 RepRap Assembly Workshop Copyability

For workshop copyability outside of universities we assume that workshop length and minimum required software knowledge must be kept low. We expect less user modifications and collaboration around the software than around the hardware because of de Brujn's findings[13]. This means that software could become an achilles heel of an early community around copyable workshops preventing its growth unless we develop robust, friendly and copyable software solutions from the outset.

1.5 Live Operating Systems

A possible way to both shorten workshop duration and lower required software knowledge could be by customizing a GNU/Linux Live operating systems. Live operating systems are loaded into portable storage media such as DVDs or USB sticks, and are bootable from there. They can be run temporarily by almost any common computer, without changing or depending on previously installed software. This trades away all installation procedures for a the storage media and the boot configuration. GNU/Linux Live systems can easily be made to copy themselves onto more DVDs and USB sticks once booted. This would make up for the added hardware by making it easily and locally copyable. For an overview of how custom Live systems can serve narrow communities' needs, see [15].

Previous examples of Live Operating Systems configured to portably run a narrow category of applications to serve communities such as makers, bioinformatics researchers, scientific computing researchers and matematicians include Makeian[16], MASSyPup[17], KNOPPIX/Math [18], ClusterKnoppix[19], Bio-Linux[15] and TAILS[20]. The data-intensive field of bioinformatics has been very active in configuring Live systems and summaries of their work are given in [21] and [22].

Four technical factors make specialized Live Systems increasingly attractive in 2016. First, most laptop computers now support the same 64-bit processor architecture. Increasing support beyond 50 % of all used laptops makes executables increasingly portable. Second, lower price and less technical constraints have made more RAM available to laptop operating systems, with 4 GiB or more being fairly standard. This allows small but complete operating systems to fit comfortably in RAM, eliminating the need for extra read/write cycles to portable media when Live System is running, making it very responsive. Third, processor clock frequencies and hence processor requirements for running new applications are not increasing as quickly as before. According to Microsoft's recommendations, a laptop capable of running Windows 7, released in 2009, should be able to run Windows 10, released in 2015[23, 24]. This means old laptops stay relevant for longer time, and the majority of Americans already own a laptop capable of running a modern Live System. Lastly, the USB3 standard is used in most laptops produced ca 2011 or later. This allows those laptops to load a Live System from a USB3 stick into RAM much faster than what was possible with USB2 sticks and DVDs. As a result of these four factors, we expect a Live System in 2016 to boot and run quickly on many of the laptop computers that people already own.

1.6 Research Question

We have described increasing labour productivity, its limited effect on real median wages, copyability of machines, RepRap 3D printers, RepRap assembly workshops, the problems of shortening them and minimizing required software knowledge and the possible solution of configuring Live operating systems. We have thus motivated the following research question:

> Can RepRap assembly workshops be shortened to one day without decreasing their copyabiliy by packaging and delivering all the needed software inside a Live Operating System?

2 Method

2.1 Overview

The research question was tested through trial-and-error. A Live System was configured in Sweden and transferred to Open Source Ecology (OSE), a small organization in Missouri. They used it in a one-day RepRap assembly workshop. After the workshop, participants were asked to fill out a web survey with questions, see Appendix D. We separately tested booting the Live System from a USB stick on a range of different laptop models in Sweden, noting down if they would cause trouble in a workshop situation.

2.2 Subjects

The main subjects of the study were the Live OS, Open Source Ecology who hosted the workshop and the participants who filled out a web survey. The Live OS was configured, had some programs packaged and was tested before the workshop.

2.2.1 Open Source Ecology

OSE's role was to test the Live System's fitness for workshop usage. They had previous experience with hosting assembly workshops for tractors and other large machines, and had a limited working experience with desktop 3D printers from before. They had little or no experience with software development, GNU/Linux administration, Live Operating systems or concepts behind 3D printer related software. OSE's Internet connection was slow and unreliable during development. The experiment therefore highlighted aspects of usability and transferability for both host and participants.

OSE's motivation was twofold. As an organization they depended on workshop revenue to support further activity. They also work actively to spread free, libre and open source machines, methods and ethics, including their enterprise activities. The workshop was the first in a planned series of workshops indended to make participants capable of building and producing with machines but also hosting workshops themselves. OSE call this type of enterprise a *distributive enterprise*[25, 26] and the 3D printer workshop was part of a larger project called *Distributive 3D Printing Enterprise*, often shortened to D3D. For more on D3D and distributive enterprise work in OSE, see [27, 28].

2.2.2 D3D-Porteus Live Operating System

Keeping size down was a major priority throughout choice and customization of live system because of OSE's slow internet connection and because we wanted to load the intire system into RAM. A RAM-only system has two benefits. First, it gives the possibility to boot the Live system and then remove the portable media that hold the Live System. This will save a workshop host if there are too few USB sticks or DVDs for all the participants. Second, RAM is fast and will make the system feel responsive in use.

Porteus was chosen as a basis among many good GNU/Linux live distros because it was minimal, could be loaded to and run from RAM, was actively maintained and easy to remaster. It also included a script that loaded Porteus onto a USB stick without overwriting it.

Other live distros such as Knoppix and PuppyLinux share many of these qualities but the Porteus web page also offered a graphical interface to easily start a custom system build[29]. This gave Porteus a head-start at meeting our customization needs. The transparent package system was also considered helpful for customization. Its basic concepts are briefly described in Appendix C.

The customized Porteus system was dubbed D3D-Porteus referring to its place in the Distributive 3D-printing enterprise project at OSE, see [30].

The web interface gave us a 250 MiB ISO image as a starting point. The parameters chosen in the Porteus system builder are listed in table 1 and some of them are briefly commented in Appendix B.

We developed both 32-bit and 64-bit systems but only the 64-bit version was used in workshop. The files for the 64-bit version are hosted at [31].

A special boot mode called *D3D Workshop Mode* was specified in `boot/syslinux/porteus.cfg`. It enabled copying to RAM and automatically executing the graphical program Pronterface on boot. Pronterface is part of Printrun described below. See [32] for all boot flags used and [33] for explanations.

The installation instructions were compiled and published at [34] to help hosts create Live USB sticks with D3D-Porteus.

2.2.3 Programs

We chose to package and include the following programs in D3D-Porteus:

- Marlin[35]

- Arduino IDE[36]

- OpenSCAD[37]

Table 1: Parameters chosen at [29] when building D3D-Porteus.

Name	Value
Architecture	64-bit
Type	EFI
Boot Mode	GUI
Desktop	XFCE
Timezone	US/Central
UTC Support	Yes
Keyboard Layout	English (US)
Sound Volume	75 %
Web Browser	Firefox
Word Processor	None
VoIP Client	None
Development Tools	Yes
Video Card Driver	Open Source Drivers
Printing Support	None

- Slic3r[38]

- Printrun[39]

They were all chosen because they are widely used within the RepRap community. Arduino IDE, OpenSCAD and parts of Printrun were compiled from source. Technical aspects of the compilation process is outside of the scope of this paper but the packaging process is briefly described in Appendix C.

Marlin is a RepRap firmware, that is the program that the little processor on the RepRap iself is running. Arduino IDE is capable of compiling and uploading Marlin to a RepRap. OpenSCAD is a program for making 3D models by scripting. Slic3r is capable of translating 3D models to RepRap commands that Marlin understands. Printrun is capable of establishing a connection between a laptop and a RepRap with Marlin, and also send commands or whole files of commands as generated by Slic3r.

All the D3D-Porteus specific configuration of these programs were put in a separate package called `D3D_Workshop_Configuration_64-bit_4.xzm`. These configurations were aimed to save in on required clicks to do the standard workshop tasks of uploading firmware and starting a test print. With the configuration in place each of these tasks took 5-7 clicks each.

No code outside of configuration files were changed.

2.2.4 Workshop and Participants

The workshop was conducted March 19, 2016 at the Kauffman Foundation Conference Center, Kansas City. It had 16 participants, 3 instructors from OSE, 12 unassembled Folgertech 2020 Prusa i3 kits, and 12 USB sticks loaded with 64-bit D3D-Porteus. OSE's marketing prior to the workshop had targetted people with an interest in hosting workshops but no particular skill level or age.

Participants were between the ages of 20 and 70 and of mixed technical skill level. Instructors had not participated in D3D-Porteus development and had limited experience with GNU/Linux administration, Live Operating Systems and 3D printer related software in general.

2.2.5 The Web Survey

The web survey that users were asked to fill out after the workshop can be found at [40]. A copy is included in Appendix D.

Since the number of data points was expected to be few, long answers were allowed on almost all questions.

2.3 Measures

A qualitative thematic analysis, grouping, counting and commenting on the different raised themes was conducted.

2.4 Procedures

2.5 Workshop Usage

The workshop started with the machines clearly un-assembled, almost all screws unscrewed, almost all wires disconnected, some solderings unsoldered. Participants were instructed to go assemble mechanics, electronics and software in that order. Machanics were subdivided into modules and a large part of the mechanical assembly had video instructions.

Booting and using D3D-Porteus was planned as the last step in the process, to be instructed when participants' machines had their mechanics and electronics ready for testing. Participants then had to boot pre-configured Porteus USB sticks and slice and print a ready-modelled rectangular block through Pronterface. Contrary to what was planned during D3D-Porteus development participants also had to compile and upload Marlin themselves.

3 Results

3.1 Pre-Workshop and Copyability

HTTP transfers of D3D-Porteus ISO from Sweden to Missouri were unsuccessful. Dropbox was successfully applied as backup transfer solution.

OSE successfully loaded D3D-Porteus onto an initial USB stick using instructions at [34]. They managed to compile and upload Marlin, connect to the RepRap and print a test cube without further instructions. They also managed to copy D3D-Porteus onto multiple USB sticks for participants without further instructions.

3.2 Workshop Usage

The workshop went over time but many reached the step of testing D3D-Porteus.

3.3 Thematic Analysis of Survey Responses

Six participants filled out the survey and the response rate was 0.375.

3.3.1 D3D-Porteus Functionality

Two participants were unable to boot on Macbook laptops.

> "...my older Macbook Pro didn't boot from the USB stick"

> "...getting the D3D Live Linux ISO to boot on my borrowed MacBook did not work, it had something to do with the OSX version () and EFI bootloader, so I had to borrow someone else's laptop which slowed both of us down..."

Another participant missed the firmware upload step and thus failed connect with Pronterface.

3.3.2 Time Shortage

Participants were frustrated by time shortage, which is visible in Figure 4.
The following comments were made on time shortage of the workshop.

> "I'm not computer or tech savvy so felt rushed.
> ...
> For me it would have been better to do the workshop over 2 days."

15
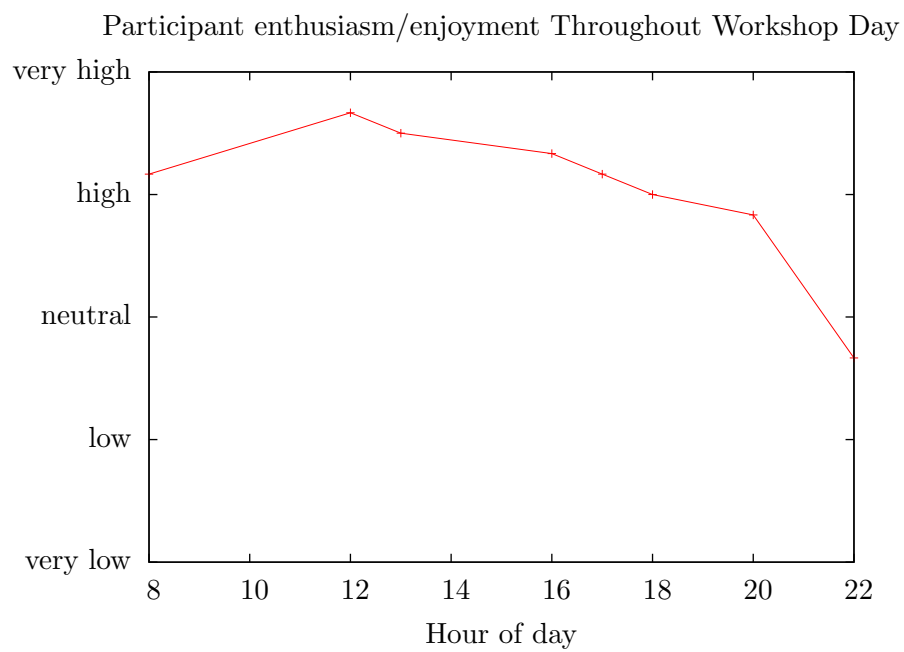
Figure 4: Participants were asked to recall their feeling of "enthusiasm/enjoyment" at various times of the workshop day and rate it along a five-step scale. The plot shows the mean of their answers, assuming a linear scale.

"The conclusion wasn't smooth - it went overtime and had to change locations"

Q: What was your least favorite part of the workshop, and why?
"Time! Integration and evaluation of experiences is extremely important. . .
. . . at times it seemed people felt rushed . . . "

". . . I didn't feel like I could help others most of the time because I didn't want to fall behind the group."

3.3.3 Autonomy and Mastery

Four of six regarded software as the link in their 3D printing toolchain that was most likely to break in ways that they were unable to debug or repair. One regarded all of mechanics, electronics and software to be likely to break in such ways. The last participant regarded electronics as most likely to break in such ways.

Q: How would you rate your instructors? Did you feel you got sufficient support? What was missing? "Definitely spread thin on instructor ratio regarding software, computer setup"

Q: What was your most favorite part of the workshop, and why? "seeing it move for the first time, "I built this""

The part that was rated second most challenging was electronics wiring.

3.4 Copyability

3.5 Instructor Comments

Host and head of OSE, Marcin made the following conclusive comment

"Software remains to be addressed. Half the people had issues with the live USB, perhaps the 32 bit version could have helped - but not for certain, as nobody had an older computer."[41]

4   Discussion

Live Operating Systems is a fairly general purpose techonology, so harvesting its potential gains requires adjusting the process in which it is used. One obvious potential is including step-by-step manuals, demonstrational videos and all sorts of documentation and multimedia that participants need during an assembly workshop. Utilizing this potential would require booting the Live System at the beginning of the assembly workshop instead of towards the end. It could give participants a distraction-free computing environment and give them the time to get comfortable with the graphical interfaces of the software. A design and test of a Live System for such software-first assembly workshop usage would be interesting future work.

Live Operating Systems could also potentially give participants channels to communicate with each other. It could for example be a chat-program or a common working document accessed via a local network or the Internet. We believe connecting participants socially is essential making workshops enjoyable enough that participants want to become hosts later. It would be very interesting to test a few simple strategies for promoting a positive group dynamics, with or without the Live Operating System as a tool.

A third potential gain from Live Operating System usage could be avoiding Internet dependence. This could make workshop locality an easier and cheaper problem for hosts and remove distracting elements from participants' screens. It would also eliminate the risk of wasting time on Internet connectivity problems. It would be interesting to measure these effects on cost, distraction and time usage and find examples of situations where Internet independence would be a relevant simplification.

One aspect of D3D-Porteus usage that we did not investigate was how to best treat system changes. Since the whole system lives in RAM memory, we have to decide what and when to save anything to disk. The current default choice is to never write automatically to disk, which most users will experience as "nothing is saved, system is restored upon reboot". This has the advantage that unintentionally broken systems can be trivially repaired. USB systems also get independent of the underlying file system (FAT requires special saving mechanisms), and their usage get almost identical to non-writeable CD/DVD systems. This is friendly towards the host. It also has the disadvantage of going against user habits and expectations. This is unfriendly towards participants. Any user could of course learn how to write changes to disk anyways, but it would be interesting to research if default automatic saving is worthwile and how to make it friendly towards both hosts and participants.

Table 2: 3D printers registered on `3dhubs.com` sorted by model. Source: [42]

Model Name	Count
Prusa i3	2 352
Ultimaker 2	2 065
Replicator 2	1 412
Zortrax M200	845
Replicator 2x	817
RepRap	724
Ultimaker 1	666
Form1+	658
FlashForge Creator Pro	624
Printrbot Simple Metal	491
Makerbot Replicator 5th Gen	441
Da Vinci 1.0	431
Robo 3D printer	384
Mendel Prusa	348
Rostock MAX	339
Prusa i3 Hephestos	335
Makergear M2	308
Other	16 898
Total	30 138

A Approximating the Number of Prusa Machines in May 2016

A very rough approximation can be made based on only two data sources 3D Hubs and Thingiverse. The strength of these data is that it is self-reported by 3D printer users rather than manufacturers, allowing home-copied machines to be counted.

Many owners of 3D printers register their machines on `3dhubs.com`, who release monthly data on model number and distribution on `3dhubs.com/trends`. The model numbers of May 2016 are presented in table 2. Assuming that they are representative, these numbers suggest that 10 % of all home 3d printers are either Prusa i3, Mendel Prusa or Hephestos Prusa i3.

The popular CAD sharing web site Thingiverse claims on their website (accessed 10 May 2016) that they have 867 690 "community members". We can use this number to estimate the number of 3D printers worldwide, including

old, broken and unused machines by assuming that most historical 3D printer owners are Thingiverse community members and most of those who don't own a 3D printer have never register an account on Thingiverse. This assumption is obviously not perfect since one can create an account without owning a 3D printer or even own several 3D printers without creating an account. On the other hand, Thingiverse is widely used within the 3D printing community and has been since its launch in 2008.

The error from competing CAD sharing sites is expected to be small. Alexa is a company who ranks web pages based on estimeted unique visitors and page views[43]. It ranks `thingiverse.com` as the 2 956'th most popular website on the Internet. The only competing 3D printing specific CAD sharing site among the one million most popular is `youmagine.com`, which ranks at 93 568'th place. Numbers retrieved from `alexa.com` at 11 May 2016.

To sanity check the Thingiverse based estimate, we can use numbers from the Wohlers Report 2016[44]. It estimates that ca 580 000 3D printers under $5000 were sold before 1 Jan 2016, with 278 000 of them in 2015 alone and with doubling numbers every year from 2012 to 2015. This trajectory gets us to 780 000 machines around the time this is written (10 May 2016). Wohler's numbers concern the number of 3D printers *sold*, a process that many home-copied RepRap machines never formally goes through.

Thingiverse user count and 3D Hubs statistics suggests ca 87 000 Prusa i3, Hephestos Prusa i3 and Prusa Mendels combined worldwide. It is surprising that the Prusa i2 does not show up in 3D Hub's statistics since its popularity at its peak was comparable to the peaks of Prusa Mendel and the current Prusa i3.

B Porteus Basic Configuration

EFI and its successor UEFI are interfaces between operating systems and computer firmware that affect booting. Most laptops from 2011–2015 support both EFI/UEFI and the older BIOS interface, but many newer laptops are unable to boot operating systems without EFI/UEFI supportal. A Porteus image with EFI support still also supports BIOS, so the EFI option only increases portability.

XFCE gave a simple desktop environment, simple windows and a simple start menu. It was also the smallest available pre-packaged GUI, ca 10 MiB smaller than the pre-packaged LXQt. Timezone and keyboard layout was set to suit workshop participants in Missouri, USA. Firefox and open source video drivers were chosen because they gave the most free software.

C Package Usage in Porteus

A *package* in a GNU/Linux system is generally a file that contains a set of compressed files and directions on where to place them in the file system. The act of decompressing and placing files according to package directions is called *package activation* in Porteus. The reverse action, namely removing a package's files from a file system is called *package deactivation*. The programs `activate` and `deactivate` are included in Porteus to do these two actions. They are applied through the terminal or by double-clicking packages in the file browser. Porteus packages use the file extention `.xzm` by convention.

To create a package, one needs the files that are to be placed and a directory structure that reflects the file system in which the files are to be placed when the package is to be activated. For example, to create a package that placed the file `/filename.foo` in the directory `/home/guest` upon activation, one would do use the following commands.

```
mkdir package_root
mkdir -p package_root/home/guest
cp /filename.foo package_root/home/guest
dir2xzm package_root my_package.xzm
```

The first command creates the directory in which we will build the package. When the package later gets activated, `package_root/` will be changed to just `/`, and the contents we now put in `package_root` will be copied to the file system. The second command creates desired directories that the package should know about or create. The third command puts a copy of our file into the desired position in the package. The last command compresses `filename.foo` and creates placement directions according to the directory structure inside `package_root`.

D Web Survey

3D Printer Workshop - Followup Survey

Thank you for participating in a 3D Printer 1 Day Build Workshop by Open Source Ecology. This survey is intended to gather learnings on the workshop, so that it can be improved in the future. Further, Torbjorn Ludvigsen - remote collaborator from Umeå University in Sweden - is using this data for his Master's Thesis (http://bit.ly/1U6wbM7) - exploring the 3D Printer as a Distributive Enterprise.

This survey takes 12 minutes to complete. Your name and email is optional if you'd like to keep your answers confidential. Results will be published openly for learning purposes - for other potential workshop organizers. You can view the responses by clicking on the Survey Results link below the survey.

1. **What is your name**
   optional

   ....

2. **What is your email address?**
   optional

   ....

3. **What is your Facebook and LinkedIn page?**
   So we can connect to you.

   ....

4. **What did you like about the workshop?**

   ....
   ....
   ....
   ....
   ....

5. **What did you not like about the workshop?**

....
....
....
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6. **What is the most important thing that you learned?**

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7. **What are your improvement suggestions?**

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....

8. **Will you be hosting a workshop in the future?**
   Mark only one oval.

   ( ) Yes

   ( ) No

   ( ) Maybe

9. **If you will be hosting a workshop, what support do you need to make that happen?**

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....
....
....

10. **If you will be hosting a workshop, what do you consider to be the biggest challenge that you will have to address to run a successful workshop?**
Venue? Marketing? Your skill set? Assistace? Part sourcing? Time commitment? Etc.

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11. **How would you rate your instructors? Did you feel you got sufficient support? What was missing?**

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....

12. **How did you feel during the workshop day? Rate your overall enthusiasm/enjoyment throughout the day.**
Mark only one oval per row.

	very low	low	neutral	high	very high
8 AM	⬭	⬭	⬭	⬭	⬭
12 AM	⬭	⬭	⬭	⬭	⬭
1 PM	⬭	⬭	⬭	⬭	⬭
4 PM	⬭	⬭	⬭	⬭	⬭
5 PM	⬭	⬭	⬭	⬭	⬭
6 PM	⬭	⬭	⬭	⬭	⬭
8 PM	⬭	⬭	⬭	⬭	⬭
10 PM	⬭	⬭	⬭	⬭	⬭

13. **What was your most favorite part of the workshop, and why?**

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14. **What was your least favorite part of the workshop, and why?**

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15. **Were participants able to help each other out? Why/why not, and in what ways?**

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16. **Will you contact participants or instructors again after the workshop?**

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17. **What adjustment of workshop arrangement would let you connect to participants and instructors more easily?**

Some people like to talk while building slowly, others prefer assembly efficiently to free up the lunch break. Some love structured introductions, others prefer unorganized coffee breaks. Some like small groups other like big ones etc.

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18. **What was your most challenging part of the assembly, and why?**

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19. **Would you try to fine tune/fix your 3D printer by yourself if needed?**
    Mark only one oval.

    ( ) Yes, the workshop gave me that self confidence

    ( ) Yes, but I already had that self confidence prior to the workshop

    ( ) No

    ( ) Don't know

    ( ) Other: ....

20. **What link in your 3D printing tool-chain do you feel are most fragile (most likely to break in ways that you're unable to debug and repair)?**
    Mark only one oval.

    ( ) Mechanics: Straightness, flatness, movement smoothness, etc

    ( ) Electronics: Wire connections, replacement part availability, etc

    ( ) Software: Ability to convert 3D models to 3D printer instructions, ability to connect to 3D printer

    ( ) Don't know

    ( ) Other: ....

Tools, support and economic feasibility

21. **If you were to host a D3D workshop, what tools would you need to acquire first?**

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22. **What would you estimate as the cost of tools? Is that prohibitive in terms of cost?**

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23. **Do you know who you would ask for help with your preparations?**

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24. **How much revenue would you need to make in order to have the interest in organizing a workshop?**

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25. **In what other ways than hosting workshops would you consider for generating revenue with your 3D printer?**

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26. **Please share any other comments or suggestions.**

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E   Economics of First D3D Workshop

The workshop generated a net revenue of $4000 that were divided so that three instructors earned $1333 each. Time investment per instructor is a number that is difficult to approximate because of factors of previous knowledge. A very rough table of time investment per instructor is given in table 3. Assuming that the approximation is correct within ± 12 h for all three instructors, each of them made $37 – $111 per hour, which would qualify them as high income workers if it was sustained over longer periods of time.

Economical investments prior to the workshop are listed in table 4. The pricing scheme used is listed in table 5.

Table 3: Approximate time investment per instructor

Activity	Time consumption
Familiarization with kit	12 h
Placing orders	2 h
Pre-assembly of parts	4 h
Work hours on workshop day	10 h
Sum	28 h

Table 4: Economical investments prior to workshop

Item	Total price
3D printer hardware	$3046
Tools	$150
USB sticks	$50
Unused spare parts	$20
Room/space	Donated
Fuel to get there	$30
Lunch	Donated

Table 5: Pricing scheme of workshop

Product	Description	Price
Early Registration	Assembly and ownership of 3D printer	$599
Registration		$699
Assistant	Assembly, not ownersip of 3D printer	$150
2-for-1 Discount	2 participants, no second 3D printer	$0
Group rate	Negotiated via email	<$699
Remote Participation	Assembly guidance. No 3D printer	$300
True Fans	A 25% discount for OSE sponsors	

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