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Gentoo Linux: The Next Generation of Linux

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A particularly inspired episode of the American TV show Frasier, “They’re Playing Our Song,” features the two brothers, Frasier and Niles Crane, talking about a new jingle Frasier is composing for his radio talk show, a project whose scope has evolved into a minor symphonic work:

Niles: Whatever happened to the concept of “less is more”?
Frasier: Ah, but if less is more then just think how much more “more” will be.

One of the reasons scientific programmers love Linux is its less-is-more philosophy. We can configure it to be anything from a desktop replacement with USB port support to a blade in a large SMP compute engine to a powerful Web server. Although Linux’s market penetration in these various sectors remains to be seen, plenty of people are pumping resources into the Linux world.

The first item of business when installing a Linux system is to pick a distribution, or distro. The plethora of options includes Red Hat, Lindows, Debian, SuSe, Mandrake, Gentoo, and even the emerging Chinese standard, Red Flag. I’ve used just about every version of Linux and found that almost all suffer at some point from the same management complexity found in Microsoft Windows. This is important for those of us who don’t want to spend a lot of time becoming Linux experts.

In this article, I’ll explain why Gentoo Linux is a good choice for scientists, and how its structure gives us the flexibility and ease of management we need.

Gentoo Linux

I should point out early on that I’m the pickiest of users. I want my systems to run optimally for scientific and computer-science research; toward this goal, I want the OS and its applications to do nothing that affects my setup’s performance and reliability. In my experience, most Linux distros are weak in certain areas:

- Binary packages. Virtually all OSs—and most Linux distros—are shipped with precompiled binaries. This means that upgrading a particular tool usually requires a full OS upgrade because most packages have numerous dependencies.
- Kernel compilation. Linux distros typically have a kernel precompiled to run on all of a particular architecture family’s machines. On the Intel x86 platform, for example, the kernel is typically configured for the 386 or 586 variants. However, many processors run less than optimally when running these instruction sets. In particular, Intel’s latest Pentium 4 and Itanium are hobbled when the kernel doesn’t use newer instructions and optimization opportunities.
- Differing platform use. Most Linux distros allow optional desktop setups, but different approaches to managing the OS exist, depending on intended use. A desktop system, for instance, requires USB devices that have the ability to plug or unplug a device at any time, as well as other peripherals to provide a more user-friendly experience.

Gentoo Linux is a significant distro for several reasons. First, the entire OS is maintained from source code. Even when binary packages are directly installed, metadata shows precisely how the package was configured and built. Second, we need install the OS only once. We can get upgrades of the latest packages from one of the myriad Gentoo mirrors. Finally, it’s completely free, regardless of intended use and configuration. Unlike Red Hat Linux, Gentoo Linux doesn’t have a commercial edition, meaning users don’t have to worry that something might be missing in the free version.

Let’s look at some of Gentoo’s salient features.

Metadata and Portage

Perhaps the Gentoo distro’s most significant feature is its use of metadata—particularly to let us answer questions about what version of a package is installed, how that package was configured and built. Even when binary packages are directly installed, metadata shows precisely how the package was configured and built. Second, we need install the OS only once. We can get upgrades of the latest packages from one of the myriad Gentoo mirrors. Finally, it’s completely free, regardless of intended use and configuration. Unlike Red Hat Linux, Gentoo Linux doesn’t have a commercial edition, meaning users don’t have to worry that something might be missing in the free version.

Let’s look at some of Gentoo’s salient features.
distros, but Gentoo takes it to a new, network-centric level. Let’s look at an example:

$ emerge --search gcc

* sys-devel/gcc

Latest version available: 3.3.3-r6
Latest version installed: 3.3.3-r6
Size of downloaded files: 23,203 kB
Homepage: http://www.gnu.org/software/gcc/gcc.html
Description: The GNU Compiler Collection.
Includes C/C++, java compilers, pie and ssp extensions
License: GPL-2 LGPL-2.1

This example shows that I have the latest version of the gcc compiler installed (the latest version available versus installed is 3.3.3-r6). The command used to obtain the information, emerge, is part of the Gentoo system, which maintains package information and keeps the packages up to date. This command’s most brilliant aspect is that we can use it at any time to discover the latest available packages. We do this with emerge sync, which synchronizes our local Portage database with one hosted at a randomly selected Gentoo mirror site. Gentoo has invested significant effort in ensuring that its mirroring scheme is highly reliable, regardless of the selected mirror.

For the most part, we can install any package of interest simply by using emerge --search to find it. (Obviously, we need to have an idea of what we’re looking for—at least part of its common name.) Once we know the name, we can pretend to install it (by using emerge --pretend) and then install it for real, using emerge with the package name as the lone argument. Unlike most installer programs out there today, emerge lets you see the potential effect of something before you actually do it.)

Package Build Complexity

Typical system administration in Linux requires ongoing maintenance of multiple packages. Most seasoned system administrator/hackers, such as yours truly, tend to download packages from the Web and build them by hand:

./configure --{}--prefix=/usr/local
   (myriad of options)
make

make install

Only a handful of packages can be built from source code without downloading and building several dependent packages beforehand. Take, for example, the world-famous (well, at least among us geeks) Emacs editor. We can build Emacs in two ways: as a console application or as a graphical application using several different widget sets.

In the past, the system administrator would download Emacs source code from ftp.gnu.org and then invoke the configure command with several options to include programming libraries for the desired functionality. By default, Emacs is designed to be compiled as a console application. Today, however, most users want the ability to run a graphical version on their desktops. Linux users typically use Emacs with their favorite desktop (Gnome or KDE), so they want this support compiled into the Emacs binary.

With Gentoo Linux, the administrator can query the Portage metadata to determine what flags can be set to direct the build. You can find the entire list of flags (known affectionately as USE flags) on the Gentoo site in the Documentation section (www.gentoo.org/doc/). Let’s look at the flags we can use to build the Emacs package, which is already installed on my system:

gkt@develop gkt $ etcat -u emacs
[ Colour Code : set unset ]
[ Legend : (U) Col 1 - Current USE flags ]
[ : (I) Col 2 - Installed With USE flags ]
U I [ Found these USE variables in : app-editors/emacs-21.3-r1]
  + - X : Adds support for X11
  + + nls : unknown
  + - motif : Adds motif support
     (x11-libs/openmotif x11-libs/lessif)
  - - leim : Adds input methods support to Emacs
  + - gnome : Adds GNOME support
  - - Xaw3d : Adds support of the 3d athena widget set
  - - debug : Tells configure and the makefiles to build for debugging.

The etcat command is part of the Gentoo Linux toolkit, which lets us examine the metadata. The U column indicates how the package would be built if we used the default USE flags (specified in the configuration file /etc/make.conf); the I column indicates how the package was actually built. On my system, which is running the etcat command, I dis-
abled X11 support and opted for a pure console application.
Here's the kicker: Suppose I decide later that I want an installation of Emacs that supports both the console and the Gnome desktop using the Gnome Toolkit (GTK) library. I can pretend to build the Emacs package from the command line using the `emerge` command discussed earlier:

```
gkt@develop gkt $ USE="gnome" emerge -up emacs
```

Pretending is what differentiates Gentoo from most other Linux distros. As you can see from the following output, adding Gnome support on my server would require me to install many packages:

```
root@develop gkt # USE="gnome" emerge -up emacs
```

These are the packages that I would merge, in order:

```
Calculating dependencies...done! [ebuild U ] dev-libs/libgdbm-1.10.2 [2.1.1]
[ebuild U ] sys-libs/gdbm [1.6.6] [2.1.1]
```

... Many lines omitted for brevity's sake!

This command might look odd to casual Unix users. Essentially, what's happening is that a local shell variable definition is temporarily affecting the environment for the `emerge` command's execution. The definition will take precedence over the
USE variable defined in the global environment, which is set in /etc/make.conf. In normal day-to-day Gentoo Linux use, we don’t have to set the USE variable on the command line; however, it’s a handy trick when we want to ensure that a particular library (or set of libraries) is compiled into a binary.

**Sneaking Around the Emerge System**

First-time Gentoo Linux users will find themselves frustrated by something known as a masked package—so named because they can’t be built, either due to an architectural limitation or because they haven’t been tested extensively. For example, the application we want to emerge might have been tested and known to work on the Intel x86 family, but not on a PowerPC or SPARC.

Every package available via the Portage system (and emerge) provides an ebuild file, which you might have noticed in the previous emerge command output. Figure 1 shows the text for the Emacs ebuild file; you can find ebuidl on your new Gentoo system in the /usr/portage/app-editors/emacs directory. This file contains many variable definitions that control how the package is built:

- **DESCRIPTION** is a summary of why we should install the package.
- **HOMEPAGE** is where we can download the file to install it.
- **SRC_URI** is where the emerge system downloads the source during installation.
- The **LICENSE** for every package in Gentoo is clearly specified in the ebuild file, which helps us sleep at night, knowing that any package installed on the system is legal, from an open-source perspective.
- **KEYWORDS** are where we see firsthand the interaction with the USE flags. Emacs, for example, can be built on just about any system, including x86, PowerPC (ppc), and SPARC (sparc). However, it can’t be built on Gentoo Linux running on an Alpha, which more than likely means that someone at Gentoo or in its user community tried it without success.
- **DEPEND** describes the dependency tree for compiling the package. The syntax is a somewhat complex beast based on regular expressions.

For brevity’s sake, I can only provide an introduction here, but knowing just a bit about how the Ebuild files work can...
prove helpful when troubleshooting the packages that fail to build properly—a rare event in Gentoo—or adding your own packages. Gentoo’s greatest strength as a Linux distribution is that it is community-focused, allowing software developers anywhere to contribute their own packages and make them available through the intuitive **emerge** command.

**Install the Kernel Yourself and Be Happy!**

Gentoo Linux is one of the few Linux distros that insists we build a proper kernel on our own, which means we don’t get a precompiled kernel under any circumstances. At first, you won’t be thrilled with this idea, but if you use any other Linux distro and find yourself wanting to rebuild the kernel, you might end up at a loss. Worse, most Linux distributions make it difficult to upgrade the kernel without basically waiting for an upgrade CD (the Microsoft approach), reinstalling new packages, and rebooting your computer.

Because the kernel is the code at the nucleus of any operating system, building it sounds scarier than it really is. Gentoo Linux provides first-time users with a script that configures the kernel exactly as the Gentoo development team has it configured on the distribution media. The program, **genkernel**, will automatically set up the kernel with the most commonly needed options and perform an optimized build for your particular processor.

**Initialization Scripts**

Initialization scripts present one of the biggest headaches when it comes to managing Linux systems, but they’re essential for bringing up the needed system services in the proper order. Such scripts are typically found in the `/etc/rc.d/rcN.d` directory, where `N` corresponds to a numbered run level. (In my experience with Solaris and Red Hat Linux systems, a server typically runs at run level 2 or 3.) The entries in the `rcN.d` directory are actually symbolic links to shell scripts in the `/etc/init.d` directory.

Figure 2. The script for `/etc/init.d/apache2`. This script starts, stops, or restarts the server at boot time.
(The actual names and numbers don’t matter, provided the network script name lexicographically precedes the Apache script name.) The init process is a bit cumbersome for a system administrator (especially at the command line) because it places a great premium on clever script names and rebooting the system to ensure it really comes up correctly after any change.

The Gentoo Linux folks have developed a superior approach for managing the complex (and often unknown) interactions between startup scripts. They defined a pattern for organizing the script, a sample of which is shown in Figure 2. This figure shows four functions: depend(), start(), stop(), and reload(). The depend() function provides details of how the service is to be run. Without going into excessive details, the service needs networking (need net) before starting. This makes sense: we need networking to start a Web server. The service also uses other services (dependent services)—for example, the default Apache setup script needs MySQL, DNS, Logger, and network mounting. Finally, Gentoo also gives us the ability to specify that a service should start after another service, even if the service doesn’t depend on that service’s availability. The big innovation is that Gentoo lets every script provide partial ordering information that can be sorted topologically to establish an execution order automatically and at runtime. This saves the system administrator from having to devise a creative naming scheme for ensuring that services start as expected.

Most packages, when emerged, provide a startup script (known historically in Unix as “rc” scripts) named after the package itself—for example, the apache2 package provides a script bearing the same name. Gentoo does not require the system administrator to actually create the script, but after emerging the package, he or she must install the script separately using the rc-update command and indicate the run levels at which the script is to be started. Gentoo Linux provides multiple run levels (boot, nonetwork, and default), so you’ll probably boot the OS at the default when setting up your own Gentoo Linux system. Here’s how to install the apache2 service:

```
/usr/sbin/rc-update add apache2 default
```

Gentoo Linux automatically recomputes the correct order in which the scripts are to be started and starts apache2 according to the constraints established in the depend() function. It’s also possible to uninstall a service without uninstalling the package: instead of using the rc-update add command just listed, you simply use the del command.

The ability to manage startup scripts so easily and intuitively is a major advance over other Linux distributions and a huge win for managing several Linux systems consistently and coherently.

**Install What You Need, Then What You Want**

Unfortunately, we’re in an age of more is more. With the potential for terabytes of disk space and gigabytes of RAM, does it matter how much disk space and memory are consumed when there’s seemingly plenty to burn? Why not just install the veritable cornucopia of free software packages and be done with it? In practice, this mentality leads to installing a bunch of stuff on your system that you simply don’t need. True, you might have resources to burn, but unwanted services running in the background still affect system performance, often dramatically.

With Gentoo Linux, a minimal but fully usable system is installed when performing the base stage3 installation (see the “Getting Started” sidebar). The stage3 installation is a minimal Gentoo setup that gets the system going without having to compile absolutely everything from scratch (which can take a long time even on the fastest systems). Notably, the base system contains only the most essential materials for building other packages: basic Unix commands, the gcc compiler (with support for C and C++), the standard C and C++ libraries, and the Portage system. Most users will want more, even those of us who truly believe that less is more. I tend to do a lot of Python hacking (part of the base system), Web programming (emerge apache2), and work with scientific programming tools. Here are the commands for installing some of my favorite scientific programming packages:

- **MPICH** emerge sys-cluster/mpich
- **LAM MPI** emerge sys-cluster/lam-mpi
- **HDF** emerge dev-lib/hdf or emerge dev-lib/hdf5
- **LAPACK** emerge app-sci/lapack

When in doubt, use `emerge -search package-name-substring`, where you type a few characters of the package name in place of `package-name-substring`. This gives you a list of matches from which you can then perform an `emerge` similar to the above examples.

You might argue that you could spend a substantial amount of time selecting which packages are or aren’t necessary. There’s really no solid counterargument to that, but I want as few inessential packages installed on my computers as possible. I’m willing to pay the price of having to install something later that I truly needed but originally forgot to install. Using the Portage tools, I can find all the installed packages I consider useful and use this list to clone the setup on another system in my cluster. The Gentoo community knows
that not all users want to exert such fine-grained control, so it’s arranging packages into groups to allow a collection of related packages to be installed in one fell swoop. The Portage system is so flexible that there’s no reason such convenience can’t be extended to users. Two predefined groups of packages—system and world—refer to essential system packages and all packages that have been installed to date, respectively. With these names, the user can periodically update packages (after synchronizing the Portage metadata) by using \texttt{emerge -update system} or \texttt{emerge -update world}. This makes the Gentoo setup’s ongoing maintenance almost (but not completely) trivial. You still need to know a thing or two about Linux system administration, but Gentoo takes the Linux world one step closer to user-friendliness when it comes to administration. Plus, its ability to reliably perform live, real-time updating from source code is unique.

**Clustering: An Advanced Need**

Let’s touch briefly on the topic of cluster computing, which is one of my present areas of research. Gentoo facilitates cluster maintenance in a variety of ways. I can’t go into exhaustive detail, but I can share my general approach to using Gentoo Linux in a clustering environment, especially a homogenous one (that is, where every system in the cluster is nearly the same in terms of hardware).

**Easy-to-Clone Reliably**

Installing Gentoo Linux in a cluster is more or less a matter of getting one of the nodes up and running. Once the node is configured as desired, we can reliably clone the setup by using a tool like \texttt{rsync} (yes, you can emerge it, if it’s not installed already) to replicate the file systems from the first node to a new node. This works a bit like magic, but Gentoo’s distro CD is a key enabler. The Gentoo folks call it a live CD because it lets you boot the OS, mount read-only file systems on the source, and then perform synchronization.

**distcc**

Cluster computing has the potential to be a killer app for Gentoo Linux. Packages can be compiled in parallel on the
need to do is edit a few configuration files (such as MPI’s)
compiling and running cleanly on Gentoo Linux; all you
into any problems with these so-called staples of HPC
established with minimal pain and suffering. I’ve never run
means that a parallel programming environment can be es-
putting (HPC)-friendly packages via the Portage system.
Perhaps one of the arguments for using Gentoo over other
Linux distros is the availability of high-performance com-
puting cluster by using the distcc service, which offloads
lengthy compiles to nodes in the cluster as they are brought
online. In my experience, this can be a significant timesaver
because numerous packages are built in parallel, especially
as I’m trying to get my system going.

Familiar Packages Available Painlessly
Perhaps one of the arguments for using Gentoo over other
Linux distros is the availability of high-performance com-
puting (HPC)-friendly packages via the Portage system.
Parallel virtual machine (PVM), message-passing interface
(MPI), and others are all available via the trusty emerge
command. For scientific programmers and scientists, this
means that a parallel programming environment can be es-
\ndablished with minimal pain and suffering. I’ve never run
into any problems with these so-called staples of HPC
compiling and running cleanly on Gentoo Linux; all you
need to do is edit a few configuration files (such as MPI’s
famous machines file to list the host names), and you’re
good to go!

Eclipse
Meanwhile, back on the other side of the world (Java), the
Eclipse Project has released version 3.0 of what is more
than likely the most impressive Java project that few peo-
ple are aware of. Eclipse is an open-source project that
emerged from IBM’s Visual Age software development.
Originaly an internal project, IBM realized that its invest-
ments in Eclipse had greater potential for payoff by involv-
ing the broader Java software development community in
extending the Eclipse platform, mostly through the cre-
ation of plug-ins and experimental projects.

Eclipse goes beyond the traditional IDE by supporting the
notion of configurable perspective—an example is a lan-
guage editing/browsing perspective. In Eclipse, perspectives
exist for Java, C/C++, and XML language editing. Another
example is a source-code repository browsing perspective,
which lets you examine a concurrent versioning system
(CVS) tree similar to Windows Explorer. The Eclipse frame-
work goes one step further by allowing for near seamless in-
tegration between perspectives—the source-code browsing
plays nicely with both Java and C code. You can easily switch
between perspectives, and Eclipse doesn’t get confused. The
Eclipse Project describes its approach as an environment for
“everything and anything or nothing in particular.”

This makes for an environment that is configurable for
just about any type of development.

Subversion
Subversion is an emerging alternative to the aforemen-
tioned CVS, which for all practical purposes, is the incum-
\bent version control software when it comes to open-
source and academic research projects. It’s not likely to go
away anytime soon, especially given the number of projects
that use it. If you judge by SourceForge use alone, there are
tens of thousands of projects actively using CVS.

CVS is not without its share of problems, especially from a
systems viewpoint. Setting up CVS to support even a small
development team requires extreme care and, therefore, ex-
pertise. Familiarity with creating users and groups on Unix is
a must, and the “setgid()” bit must be enabled to ensure
group ownership of files contained in project directories so
all members of the group can continue to check out, update,
and commit files. The Subversion Project (subversion.tigris.
org) aims to create a tool that’s mostly compatible with CVS
from the user perspective while simultaneously employing
modern systems design techniques. Instead of keeping version
files in a hierarchical directory structure (that mirrors the
project’s source hierarchy), all information is kept in a single
embedded database—specifically, the Berkeley DB storage
engine. The advantages of databases over file systems in-
clude transactional safety, consistency, and portability. In just
a short time, the Subversion team has ported its C code to all
modern OS platforms, so Windows users can also run the
Subversion server or client.

Subversion is a project worth keeping any eye on. I’m
going to hold out just a bit longer—at least for my Java pro-
jects—until the integration with Eclipse (my favorite soft-
ware tool) is completed.

OpenMosix
One of my students, Sean McGuire, actually set up our labo-
\ratory at Loyola University, Chicago, with Gentoo Linux. Be-
ing clever, he decided to experiment with a special kernel
known as OpenMosix, which allows for processes to be created
from any node and launched on any node under suitable mi-
gration conditions. OpenMosix is useful for environments that
feature batch-style parallel processing, wherein the goal is to
maximize the throughput of jobs that have minimal data I/O
requirements or transaction environments in which the I/O is
offloaded to a transaction server. Gentoo Linux again makes it
possible to take advantage of experimental kernels and software
tools that other distributions tend to avoid like the plague.

At my private company and at my university, I have
built my own low-cost computing clusters using ShuttleX
nodes (www.shuttle.com), which at the time of
this writing run approximately US$400 apiece. The
Nimkathana cluster (www.nimkathana.com/products/low
Getting Started

Getting started with Gentoo is easy. It’s a bit more work than setting up something like Red Hat, but that’s a price well worth paying, especially if you relish the thought of having a clue about what’s being installed and how to configure things. The Gentoo Linux documentation is excellent, with many helpful tips on how to do useful types of setups such as running a mail-hosting environment.

Here are the steps:

- Visit www.gentoolinux.org. It has an installation document that you’ll want to download and print. A printed version of the document on which you can write notes is extremely helpful.
- Download the ISO image to create an installation CD. This more than likely means that you should have a CD-burning utility on your computer. On OS X, you can run the Disk Utility; on Windows, a great program is Ahead Nero (www.ahead.de/us/index.html).
- The site provides many different images. For most users with modern PCs, the images having Pentium, Pentium4, or Athlon in the name should be adequate. (One tidbit: regardless of whether you use Pentium or Athlon processors, both are compatible with the 686 instruction sets.) Gentoo provides a universal CD, but you should pursue this option only if you don’t know what architecture your computer is using.
- Once you’ve burned the CD-ROM, try booting your computer with it. This might not work if your CD-ROM is disabled as a boot device, which forces you to go into the BIOS setup to enable CD-ROM booting. Usually, you need to specify the order in which the various devices should be tried. These days, you can select just about anything as a boot device. If you’ve installed Windows on your system, you might already be set to boot from CD-ROM, but check before proceeding.

Once you’re booted, you can complete the setup as described in the installation guide. The process is relatively straightforward from this point: you create partitions and file systems on the partitions, and then proceed to install the base OS. Next, you’ll build the kernel, install a bootloader (to let you boot Linux or Windows), and you’re done.

In addition to the previous steps, some questions should be on your mind:

- Do you plan to keep Windows on the same computer? This is known as the dual-boot option. If you plan to install both Windows and Linux, you should seriously think about making a backup...now.
- Do you know what hardware is in your computer? Certain devices, usually found in ultra-cheap PCs, are designed to work only with Windows. Some modems and integrated video logic don’t work with Linux and never will, but such problems can usually be remedied by replacing or adding the device in question. If you have integrated video, for example, you’ll want to go out and get a relatively standard video card that is known to work with Linux.
- Are you going to use Linux mostly in terminal mode or graphical mode? If you don’t plan on running desktop applications and just want to tinker around with Linux in console mode, you can get a setup running with minimal pain and suffering. Most of my servers are configured to run exclusively in terminal mode, which I then access remotely from my laptop running OS X (and sometimes Windows). If running in terminal mode, I strongly recommend that you install OpenSSH (which can be done with emerge and rc-update as described in the article).

My ultimate advice? Learn the answers to all these questions before attempting to install Gentoo or any version of Linux.

_gecost_clustering_, which varies between 8 and 12 nodes, is an example of such a cluster built for under $5,000, with access to a storage server built for under $2,500. We use this cluster for data mining and simulations, and it runs Gentoo Linux exclusively. Who would have thought that we could build a terascale cluster for under $5,000, let alone have access to another terabyte off-cluster for $2,500? However, the best aspect of the cluster isn’t its cost: it’s the ability to install a great Linux distro, Gentoo Linux, and keep it up to date at all times without ever having to reinstall the OS again (baring an unanticipated hardware failure).

This article only scratches the surface of what’s possible with Gentoo Linux. With a robust metadata framework and network-centric architecture, the Gentoo approach provides a great example of the Internet’s potential to make OSs easier to maintain (live and in real time) and keep up to date in an age in which security has risen to the forefront of serious problems, necessitating the ability to incorporate patches before vulnerabilities are exploited. Although I didn’t cover it here, Gentoo releases its own security advisories. In short, the OS sports a modern design and is well-suited to everything from desktop to advanced computing.

George K. Thiruvathukal is an associate professor of computer science at Loyola University, Chicago. He is also president and CEO of Nimkatha Corporation, which does research and development in high-performance cluster computing, data mining, handheld/embedded software, and distributed systems. He wrote two books covering concurrent, parallel, distributed programming patterns and techniques in Java and Web programming in Python. Contact him at www.cs.luc.edu/gkt.