

Speech recognition and synthesis

1 TTS and ASR: A synthesis

- Introduction
- ASR
- HMM based TTS
- Bibliography

Copyright ©2007-2008 R.J.J.H. van Son, GNU General Public License [FSF(1991)]



Introduction

Classical

TTS: Text \Rightarrow Accents \Rightarrow Phonemes \Rightarrow Prosody \Rightarrow Sound

ASR: Sound \Rightarrow MFCC \Rightarrow HMM \Rightarrow Language Model \Rightarrow Text

TTS and ASR: Two unconnected technologies?

- Both synthesis and recognition work by comparing speech to a stored model
- Recognition works by synthesizing speech
- Synthesis works by reproducing stored speech
- Can a synthesizer really be used to recognize?
- Can a recognizer really be used to synthesize?



Introduction

New and Improved

ASR: Text \Leftarrow Accents \Leftarrow Phonemes \Leftarrow Prosody \Leftarrow Sound ?

TTS: Sound \Leftarrow MFCC \Leftarrow HMM \Leftarrow Language Model \Leftarrow Text ?

TTS and ASR: Recognize by synthesis, or synthesize by recognition

- *Both synthesis and recognition work by comparing speech to a stored model*
- *Recognition works by synthesizing speech*
- *Synthesis works by reproducing stored speech*
- **Can a synthesizer really be used to recognize?**
- **Can a recognizer really be used to synthesize?**



Introduction: The computational challenge

There is no data like more data, but how to use it?

- Computers become exponentially faster over time
- Speech corpora become exponentially larger over time
- Current HMM speech recognition only marginally better than 10 years ago
- Current synthesis idem
- How can computer speed and corpus size be harnessed?



ASR: Standard HMM

Problems in HMM

- Conditional Independent and Identical Distribution (IID)
- Speech can be described as a sequence of discrete units (phonemes)
- Strip all non-verbal (indexial) information
- Cannot use indexial information (eg, coarticulation)
- Adapt to rate, hypo/hyperarticulation
- \Rightarrow standard HMM models cannot store enough information



ASR: Structure-based approach

Model the parameters of speech production

- Establish mathematical models for stochastic trajectories or segments
- Eg, piecewise polynomials, linear dynamic systems, nonlinear dynamic systems
- Model speech dynamics i.o. acoustics (hypo/hyperarticulation, rate)
- Hidden dynamic models look at articulation
⇒ Articulatory Synthesis
- Combine hidden dynamic vectors with observed acoustic feature vectors
- ⇒ Explicitly model and train other factors



ASR: Template based recognition

Speech contains two types of information

- Verbal information
- Indexial (non-verbal) information
- Words versus Form
- HMM handles the words, but not the Form
- Form includes F_0 and speaking rate
- Form also includes speaker specific information
- Fine phonetic detail can influence recognition
- Eg, 1st syllable of *ham* versus *hamster*
- ASR model needed that can handle indexial information

ASR: Speech recognition by unit synthesis

HMM derives abstract model from examples

- Don't abstract, use examples directly
- Store speech of many speakers
- For each speaker, store lots of speech (words)
- Store different styles of speech, and label them
- \Rightarrow Template-, exemplar-, instance- based ASR



ASR: Template based

Store as much speech as possible

- Add transcriptions and labels
- Store all indexial and textual information
- What was said, by whom, and how
- Words are stored as many example feature vectors “trajectories”
- Preserving as many details as possible
- Incoming signal is compared to sequences of trajectories



ASR: Cookbook

Train knowledge sources of a template based recognizer

- 1 Segment and transcribe the training database.
The result is a segmentation file with phoneme transcriptions and phonetic boundary timings
- 2 Merge consecutive segments at will to produce supra-phonemic templates
- 3 Determine meta-information for each segment
- 4 Determine suitable transition costs to each pair of possible meta-tags
- 5 Assign suitable acoustic scaling matrices for each frame in the database
- 6 Calculate an indexing structure for fast k-nearest neighbours selection
- 7 Compute weights to combine the different knowledge sources

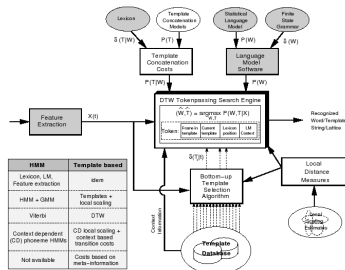
ASR: Template definition

A template is the representation of an actual segment of speech. It consists of

- a sequence of consecutive acoustic feature vectors (or frames)
- a transcription of the sounds or words it represents (typically one or more phonetic symbols)
- knowledge of neighbouring templates (a template number if no templates overlap)
- a tag with meta-information



ASR: Architectural overview



Correspondence between HMM and Template based ASR

- Distances are calculated to template cluster centroids
- Clustered acoustic vectors are a kind of degenerated HMM
- Train the costs of going from one template (fragment) to another

[De Wachter et al.(2007)De Wachter, Matton, Demuyne, Wambacq, Cools, and Van Compernelle]

HMM based TTS: The challenge of TTS

There is never enough speech

- Every utterance and situation are different
- “Expressive” speech needs even more different utterances
- Recording a new speaker for every new application is not acceptable
- Speaker time becomes limiting factor
- ... and it is never enough



HMM based TTS: Speech synthesis by HMM recognition

Unit selection is inflexible

- Speech units cannot be adapted to needs
- Abstract from specific speaker and example
- Model speech stochastically and select most likely utterance



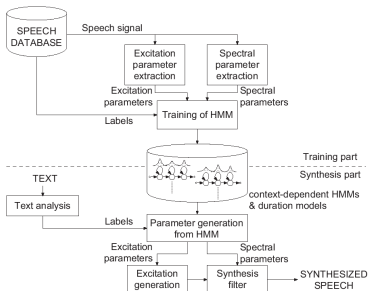
HMM based TTS: HMM models

Add a lot of flexibility

- HMM states can average over a cluster of contexts
- Store the dynamics of spectral change etc.
- HMM models for a new speaker can be learned
- New speaker or language *only* needs the difference
- The difference can be determined on just a little speech
- HMM TTS is *adaptable*
- (and you can indeed synthesize *MFCC* vectors)



HMM based TTS

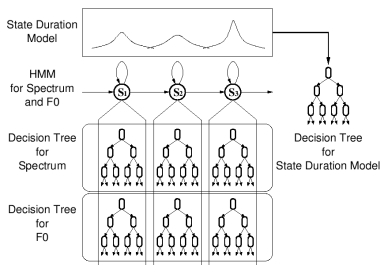


Store abstract, generalized units

- HMM states summarize spectrum words
- Model intonation (excitation) separately
- Label HMMs with contextual information

[Tokuda et al.(2002)Tokuda, Zen, and Black]

HMM based TTS:



Decision-tree based context clustering

- Many contextual factors (e.g., phone identity factors, stress-related factors, locational factors)
- Context-dependent HMMs
- Not enough speech and time \Rightarrow Cluster

HMM based TTS:

Table 1. Binary file size of HTS run-time engine.

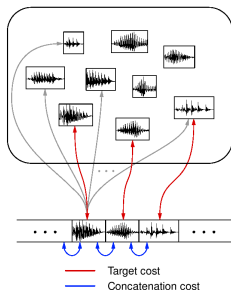
module		size
decision tree	spectrum	102 kbyte
	F_0	156 kbyte
	duration	116 kbyte
distribution	spectrum	457 kbyte
	F_0	81 kbyte
	duration	39 kbyte
converter		3 kbyte
synthesizer		34 kbyte
total		988 kbyte

Reduce footprint

- Small enough for PDAs
- Ten times Real-Time (on P4)
- HTS example using Alan's voice

[Tokuda et al.(2002)Tokuda, Zen, and Black]

HMM based TTS:

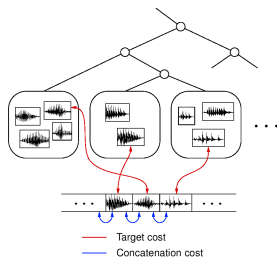


Classical Unit Selection scheme

- Concatenate using Target and Concatenation costs
- Use whole speech database
- Concatenate in real time

[Tokuda et al.(2002)Tokuda, Zen, and Black]

HMM based TTS:



HTS scheme

- Cluster all units on context in advance
- But use only statistics of cluster, not original templates
- Concatenation cost corresponds to dynamic feature parameter

[Tokuda et al.(2002)Tokuda, Zen, and Black]

HMM based TTS:

Table 2. Relation between unit selection and generation approaches.

Unit selection	HTS
Clustering (possible use of HMM)	Clustering (use of HMM)
Multi-template	Statistics
Single tree	Multiple tree (Spectrum, F0, duration)
Advantage: <ul style="list-style-type: none"> • High quality at waveform level Disadvantage: <ul style="list-style-type: none"> • Discontinuity • Hit or miss • Large run-time data • Fixed voice 	Disadvantage: <ul style="list-style-type: none"> • Vocoded speech (buzzy) Advantage: <ul style="list-style-type: none"> • Smooth • Stable • Small run-time data • Various voices

Comparison

- Unit selection often very good, sometimes really bad
- HMM often bad (vocoder)
- HMM is much smaller and adaptable (retraining)

[Tokuda et al.(2002)Tokuda, Zen, and Black]

Further Reading I



James F. Allen, Donna K. Byron, Myroslava Dzikovska, George Ferguson, Lucian Galescu, and Amanda Stent.
Toward conversational human-computer interaction.

AI Magazine, Winter, 2001.

URL <http://www.cs.rochester.edu/research/cisd/pubs/2001/allen-et-al-aimag2001.pdf>.



P. Boersma.

Praat, a system for doing phonetics by computer.

Glot International, 5:341–345, 2001.

URL <http://www.Praat.org/>.



P. Boersma and D. Weenink.

Praat 4.2: doing phonetics by computer.

Computer program: <http://www.Praat.org/>, 2004.

URL <http://www.Praat.org/>.



M. De Wachter, M. Matton, K. Demuyne, P. Wambacq, R. Cools, and D. Van Compernelle.

Template-Based Continuous Speech Recognition.

IEEE TRANSACTIONS ON AUDIO, SPEECH & LANGUAGE PROCESSING, 15(4):1377–1390, 2007.

ISSN 1558-7916.



FSF.

GNU General Public License.

Web, June 1991.

URL <http://www.gnu.org/licenses/gpl.html>.



Further Reading II



Daniel Jurafsky and James H. Martin.

Speech and Language Processing.

Prentice-Hall, 2000.

ISBN 0-13-095069-6.

URL <http://www.cs.colorado.edu/~martin/slp.html>.

Updates at <http://www.cs.colorado.edu/>



Helmer Strik, Albert Russel, Henk van den Heuvel, Catia Cucchiari, and Lou Boves.

A spoken dialog system for the dutch public transport information service.

Int. Journal of Speech Technology, 2:121–131, 1997.

URL <http://lands.let.ru.nl/literature/strik.1996.4.ps>.

Link is to an older version.



Keiichi Tokuda, Heiga Zen, and Alan W. Black.

An HMM-based speech synthesis system applied to English, 2002.

URL <http://www.cs.cmu.edu/~awb/papers/IEEE2002/hmmenglish.pdf>.



W. Wesseling and R. J. J. H. van Son.

Timing of experimentally elicited minimal responses as quantitative evidence for the use of intonation in projecting TRPs.

In *Proceedings of Interspeech2005*, Lisbon, 2005.



Wieneke Wesseling and R.J.J.H. Van Son.

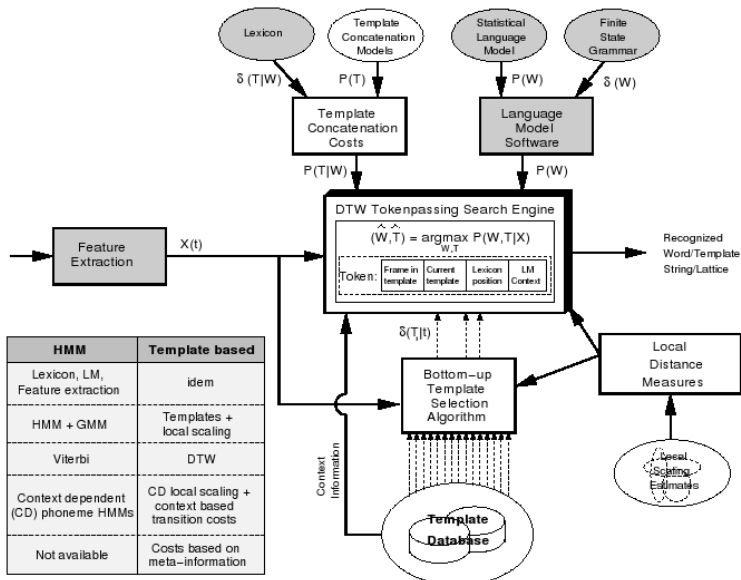
Early Preparation of Experimentally Elicited Minimal Responses.

In *Proceedings of SIGdial 2005*, September 2005.

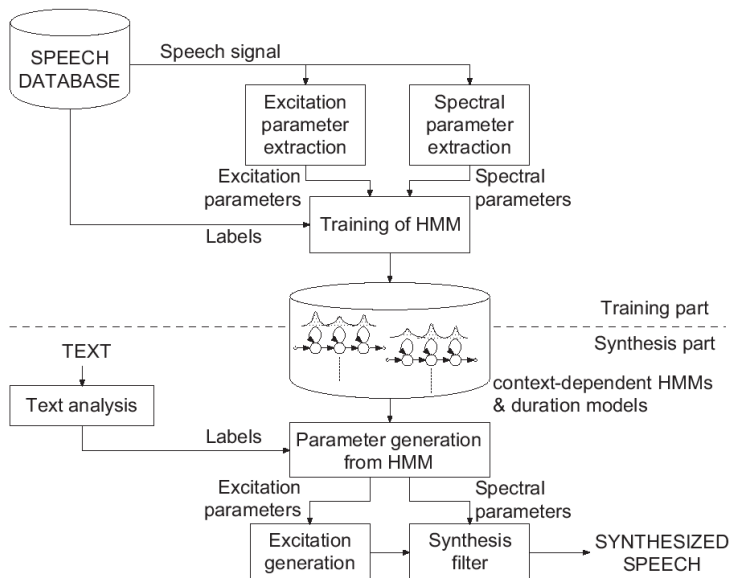
URL <http://www.fon.hum.uva.nl/rob/Publications/ArtikelSIGdial2005.pdf>.



Architectural overview template based ASR



Architectural overview HMM based synthesis



Copyright License

Copyright ©2007-2008 R.J.J.H. van Son, GNU General Public License
[FSF(1991)]

This program is free software; you can redistribute it and/or modify it under the terms of the GNU General Public License as published by the Free Software Foundation; either version 2 of the License, or (at your option) any later version. This program is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU General Public License for more details.

You should have received a copy of the GNU General Public License along with this program; if not, write to the Free Software Foundation, Inc., 51 Franklin Street, Fifth Floor, Boston, MA 02110-1301, USA.



The GNU General Public License I

Version 2, June 1991
Copyright © 1989, 1991 Free Software Foundation, Inc.

51 Franklin Street, Fifth Floor, Boston, MA 02110-1301, USA

Everyone is permitted to copy and distribute verbatim copies of this license document, but changing it is not allowed.

Preamble

The licenses for most software are designed to take away your freedom to share and change it. By contrast, the GNU General Public License is intended to guarantee your freedom to share and change free software—to make sure the software is free for all its users. This General Public License applies to most of the Free Software Foundation's software and to any other program whose authors commit to using it. (Some other Free Software Foundation software is covered by the GNU Library General Public License instead.) You can apply it to your programs, too.

When we speak of free software, we are referring to freedom, not price. Our General Public Licenses are designed to make sure that you have the freedom to distribute copies of free software (and charge for this service if you wish), that you receive source code or can get it if you want it, that you can change the software or use pieces of it in new free programs; and that you know you can do these things.

To protect your rights, we need to make restrictions that forbid anyone to deny you these rights or to ask you to surrender the rights. These restrictions translate to certain responsibilities for you if you distribute copies of the software, or if you modify it. For example, if you distribute copies of such a program, whether gratis or for a fee, you must give the recipients all the rights that you have. You must make sure that they, too, receive or can get the source code. And you must show them these terms so they know their rights.

We protect your rights with two steps: (1) copyright the software, and (2) offer you this license which gives you legal permission to copy, distribute and/or modify the software.



The GNU General Public License II

Also, for each author's protection and ours, we want to make certain that everyone understands that there is no warranty for this free software. If the software is modified by someone else and passed on, we want its recipients to know that what they have is not the original, so that any problems introduced by others will not reflect on the original authors' reputations.

Finally, any free program is threatened constantly by software patents. We wish to avoid the danger that redistributors of a free program will individually obtain patent licenses, in effect making the program proprietary. To prevent this, we have made it clear that any patent must be licensed for everyone's free use or not licensed at all.

The precise terms and conditions for copying, distribution and modification follow.

TERMS AND CONDITIONS FOR COPYING, DISTRIBUTION AND MODIFICATION

- 0 This License applies to any program or other work which contains a notice placed by the copyright holder saying it may be distributed under the terms of this General Public License. The "Program", below, refers to any such program or work, and a "work based on the Program" means either the Program or any derivative work under copyright law: that is to say, a work containing the Program or a portion of it, either verbatim or with modifications and/or translated into another language. (Hereinafter, translation is included without limitation in the term "modification".) Each licensee is addressed as "you".

Activities other than copying, distribution and modification are not covered by this License; they are outside its scope. The act of running the Program is not restricted, and the output from the Program is covered only if its contents constitute a work based on the Program (independent of having been made by running the Program). Whether that is true depends on what the Program does.



The GNU General Public License III

- 1 You may copy and distribute verbatim copies of the Program's source code as you receive it, in any medium, provided that you conspicuously and appropriately publish on each copy an appropriate copyright notice and disclaimer of warranty; keep intact all the notices that refer to this License and to the absence of any warranty; and give any other recipients of the Program a copy of this License along with the Program.
You may charge a fee for the physical act of transferring a copy, and you may at your option offer warranty protection in exchange for a fee.
- 2 You may modify your copy or copies of the Program or any portion of it, thus forming a work based on the Program, and copy and distribute such modifications or work under the terms of Section 1 above, provided that you also meet all of these conditions:
 - 1 You must cause the modified files to carry prominent notices stating that you changed the files and the date of any change.
 - 2 You must cause any work that you distribute or publish, that in whole or in part contains or is derived from the Program or any part thereof, to be licensed as a whole at no charge to all third parties under the terms of this License.
 - 3 If the modified program normally reads commands interactively when run, you must cause it, when started running for such interactive use in the most ordinary way, to print or display an announcement including an appropriate copyright notice and a notice that there is no warranty (or else, saying that you provide a warranty) and that users may redistribute the program under these conditions, and telling the user how to view a copy of this License. (Exception: if the Program itself is interactive but does not normally print such an announcement, your work based on the Program is not required to print an announcement.)



The GNU General Public License IV

These requirements apply to the modified work as a whole. If identifiable sections of that work are not derived from the Program, and can be reasonably considered independent and separate works in themselves, then this License, and its terms, do not apply to those sections when you distribute them as separate works. But when you distribute the same sections as part of a whole which is a work based on the Program, the distribution of the whole must be on the terms of this License, whose permissions for other licensees extend to the entire whole, and thus to each and every part regardless of who wrote it.

Thus, it is not the intent of this section to claim rights or contest your rights to work written entirely by you; rather, the intent is to exercise the right to control the distribution of derivative or collective works based on the Program.

In addition, mere aggregation of another work not based on the Program with the Program (or with a work based on the Program) on a volume of a storage or distribution medium does not bring the other work under the scope of this License.

- 3 You may copy and distribute the Program (or a work based on it, under Section 2) in object code or executable form under the terms of Sections 1 and 2 above provided that you also do one of the following:
 - 1 Accompany it with the complete corresponding machine-readable source code, which must be distributed under the terms of Sections 1 and 2 above on a medium customarily used for software interchange; or,
 - 2 Accompany it with a written offer, valid for at least three years, to give any third party, for a charge no more than your cost of physically performing source distribution, a complete machine-readable copy of the corresponding source code, to be distributed under the terms of Sections 1 and 2 above on a medium customarily used for software interchange; or,
 - 3 Accompany it with the information you received as to the offer to distribute corresponding source code. (This alternative is allowed only for noncommercial distribution and only if you received the program in object code or executable form with such an offer, in accord with Subsection b above.)



The GNU General Public License V

The source code for a work means the preferred form of the work for making modifications to it. For an executable work, complete source code means all the source code for all modules it contains, plus any associated interface definition files, plus the scripts used to control compilation and installation of the executable. However, as a special exception, the source code distributed need not include anything that is normally distributed (in either source or binary form) with the major components (compiler, kernel, and so on) of the operating system on which the executable runs, unless that component itself accompanies the executable.

If distribution of executable or object code is made by offering access to copy from a designated place, then offering equivalent access to copy the source code from the same place counts as distribution of the source code, even though third parties are not compelled to copy the source along with the object code.

- 4 You may not copy, modify, sublicense, or distribute the Program except as expressly provided under this License. Any attempt otherwise to copy, modify, sublicense or distribute the Program is void, and will automatically terminate your rights under this License. However, parties who have received copies, or rights, from you under this License will not have their licenses terminated so long as such parties remain in full compliance.
- 5 You are not required to accept this License, since you have not signed it. However, nothing else grants you permission to modify or distribute the Program or its derivative works. These actions are prohibited by law if you do not accept this License. Therefore, by modifying or distributing the Program (or any work based on the Program), you indicate your acceptance of this License to do so, and all its terms and conditions for copying, distributing or modifying the Program or works based on it.
- 6 Each time you redistribute the Program (or any work based on the Program), the recipient automatically receives a license from the original licensor to copy, distribute or modify the Program subject to these terms and conditions. You may not impose any further restrictions on the recipients' exercise of the rights granted herein. You are not responsible for enforcing compliance by third parties to this License.



The GNU General Public License VI

- 7 If, as a consequence of a court judgment or allegation of patent infringement or for any other reason (not limited to patent issues), conditions are imposed on you (whether by court order, agreement or otherwise) that contradict the conditions of this License, they do not excuse you from the conditions of this License. If you cannot distribute so as to satisfy simultaneously your obligations under this License and any other pertinent obligations, then as a consequence you may not distribute the Program at all. For example, if a patent license would not permit royalty-free redistribution of the Program by all those who receive copies directly or indirectly through you, then the only way you could satisfy both it and this License would be to refrain entirely from distribution of the Program.

If any portion of this section is held invalid or unenforceable under any particular circumstance, the balance of the section is intended to apply and the section as a whole is intended to apply in other circumstances.

It is not the purpose of this section to induce you to infringe any patents or other property right claims or to contest validity of any such claims; this section has the sole purpose of protecting the integrity of the free software distribution system, which is implemented by public license practices. Many people have made generous contributions to the wide range of software distributed through that system in reliance on consistent application of that system; it is up to the author/donor to decide if he or she is willing to distribute software through any other system and a licensee cannot impose that choice.

This section is intended to make thoroughly clear what is believed to be a consequence of the rest of this License.

- 8 If the distribution and/or use of the Program is restricted in certain countries either by patents or by copyrighted interfaces, the original copyright holder who places the Program under this License may add an explicit geographical distribution limitation excluding those countries, so that distribution is permitted only in or among countries not thus excluded. In such case, this License incorporates the limitation as if written in the body of this License.
- 9 The Free Software Foundation may publish revised and/or new versions of the General Public License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns.

Each version is given a distinguishing version number. If the Program specifies a version number of this License which applies to it and “any later version”, you have the option of following the terms and conditions either of that version or of any later version published by the Free Software Foundation. If the Program does not specify a version number of this License, you may choose any version ever published by the Free Software Foundation.



The GNU General Public License VII

- 10 If you wish to incorporate parts of the Program into other free programs whose distribution conditions are different, write to the author to ask for permission. For software which is copyrighted by the Free Software Foundation, write to the Free Software Foundation; we sometimes make exceptions for this. Our decision will be guided by the two goals of preserving the free status of all derivatives of our free software and of promoting the sharing and reuse of software generally.

NO WARRANTY

- 11 BECAUSE THE PROGRAM IS LICENSED FREE OF CHARGE, THERE IS NO WARRANTY FOR THE PROGRAM, TO THE EXTENT PERMITTED BY APPLICABLE LAW. EXCEPT WHEN OTHERWISE STATED IN WRITING THE COPYRIGHT HOLDERS AND/OR OTHER PARTIES PROVIDE THE PROGRAM "AS IS" WITHOUT WARRANTY OF ANY KIND, EITHER EXPRESSED OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. THE ENTIRE RISK AS TO THE QUALITY AND PERFORMANCE OF THE PROGRAM IS WITH YOU. SHOULD THE PROGRAM PROVE DEFECTIVE, YOU ASSUME THE COST OF ALL NECESSARY SERVICING, REPAIR OR CORRECTION.
- 12 IN NO EVENT UNLESS REQUIRED BY APPLICABLE LAW OR AGREED TO IN WRITING WILL ANY COPYRIGHT HOLDER, OR ANY OTHER PARTY WHO MAY MODIFY AND/OR REDISTRIBUTE THE PROGRAM AS PERMITTED ABOVE, BE LIABLE TO YOU FOR DAMAGES, INCLUDING ANY GENERAL, SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES ARISING OUT OF THE USE OR INABILITY TO USE THE PROGRAM (INCLUDING BUT NOT LIMITED TO LOSS OF DATA OR DATA BEING RENDERED INACCURATE OR LOSSES SUSTAINED BY YOU OR THIRD PARTIES OR A FAILURE OF THE PROGRAM TO OPERATE WITH ANY OTHER PROGRAMS), EVEN IF SUCH HOLDER OR OTHER PARTY HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

END OF TERMS AND CONDITIONS



The GNU General Public License VIII

Appendix: How to Apply These Terms to Your New Programs

If you develop a new program, and you want it to be of the greatest possible use to the public, the best way to achieve this is to make it free software which everyone can redistribute and change under these terms.

To do so, attach the following notices to the program. It is safest to attach them to the start of each source file to most effectively convey the exclusion of warranty; and each file should have at least the “copyright” line and a pointer to where the full notice is found.

one line to give the program's name and a brief idea of what it does.

Copyright (C) yyyy name of author

This program is free software; you can redistribute it and/or modify it under the terms of the GNU General Public License as published by the Free Software Foundation; either version 2 of the License, or (at your option) any later version.

This program is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU General Public License for more details.

You should have received a copy of the GNU General Public License along with this program; if not, write to the Free Software Foundation, Inc., 51 Franklin Street, Fifth Floor, Boston, MA 02110-1301, USA.

Also add information on how to contact you by electronic and paper mail.

If the program is interactive, make it output a short notice like this when it starts in an interactive mode:

Gnomovision version 69, Copyright (C) yyyy name of author

Gnomovision comes with ABSOLUTELY NO WARRANTY; for details type 'show w'.

This is free software, and you are welcome to redistribute it under certain conditions; type 'show c' for details.



The GNU General Public License IX

The hypothetical commands `show w` and `show c` should show the appropriate parts of the General Public License. Of course, the commands you use may be called something other than `show w` and `show c`; they could even be mouse-clicks or menu items—whatever suits your program.

You should also get your employer (if you work as a programmer) or your school, if any, to sign a “copyright disclaimer” for the program, if necessary. Here is a sample; alter the names:

*Yoyodyne, Inc., hereby disclaims all copyright interest in the program
'Gnomovision' (which makes passes at compilers) written by James Hacker.
signature of Ty Coon, 1 April 1989
Ty Coon, President of Vice*

This General Public License does not permit incorporating your program into proprietary programs. If your program is a subroutine library, you may consider it more useful to permit linking proprietary applications with the library. If this is what you want to do, use the GNU Library General Public License instead of this License.

