

# Octave C++ Classes

---

Edition 1.0 for Octave version 4.4.0  
September 1993

**John W. Eaton**

---

Copyright © 1996, 1997 John W. Eaton.

This is the first edition of the documentation for Octave's C++ classes, and is consistent with version 4.4.0 of Octave.

Permission is granted to make and distribute verbatim copies of this manual provided the copyright notice and this permission notice are preserved on all copies.

Permission is granted to copy and distribute modified versions of this manual under the conditions for verbatim copying, provided that the entire resulting derived work is distributed under the terms of a permission notice identical to this one.

Permission is granted to copy and distribute translations of this manual into another language, under the same conditions as for modified versions.

# Table of Contents

<b>1</b>	<b>Acknowledgements .....</b>	<b>1</b>
	Contributors to Octave .....	1
	<b>GNU GENERAL PUBLIC LICENSE .....</b>	<b>2</b>
<b>2</b>	<b>A Brief Introduction to Octave .....</b>	<b>13</b>
<b>3</b>	<b>Arrays .....</b>	<b>14</b>
	3.1 Constructors and Assignment .....	14
<b>4</b>	<b>Matrix and Vector Operations .....</b>	<b>18</b>
<b>5</b>	<b>Matrix Factorizations .....</b>	<b>33</b>
<b>6</b>	<b>Ranges .....</b>	<b>37</b>
<b>7</b>	<b>Nonlinear Functions .....</b>	<b>38</b>
<b>8</b>	<b>Nonlinear Equations .....</b>	<b>39</b>
<b>9</b>	<b>Optimization .....</b>	<b>40</b>
	9.1 Objective Functions .....	40
	9.2 Bounds .....	40
	9.3 Linear Constraints .....	41
	9.4 Nonlinear Constraints .....	41
	9.5 Quadratic Programming .....	41
	9.6 Nonlinear Programming .....	42
<b>10</b>	<b>Quadrature .....</b>	<b>43</b>
	10.1 Collocation Weights .....	43
<b>11</b>	<b>Ordinary Differential Equations .....</b>	<b>45</b>
<b>12</b>	<b>Differential Algebraic Equations .....</b>	<b>46</b>
<b>13</b>	<b>Error Handling .....</b>	<b>47</b>

<b>14</b>	<b>Installation .....</b>	<b>48</b>
<b>15</b>	<b>Bugs .....</b>	<b>49</b>
	<b>Concept Index .....</b>	<b>50</b>
	<b>Function Index .....</b>	<b>51</b>

# 1 Acknowledgements

## Contributors to Octave

In addition to John W. Eaton, several people have written parts of liboctave. (This has been removed because it is the same as what is in the Octave manual.)

# GNU GENERAL PUBLIC LICENSE

Version 3, 29 June 2007

Copyright © 2007 Free Software Foundation, Inc. <https://fsf.org/>

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

## Preamble

The GNU General Public License is a free, copyleft license for software and other kinds of works.

The licenses for most software and other practical works are designed to take away your freedom to share and change the works. By contrast, the GNU General Public License is intended to guarantee your freedom to share and change all versions of a program—to make sure it remains free software for all its users. We, the Free Software Foundation, use the GNU General Public License for most of our software; it applies also to any other work released this way by its authors. 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 them 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 prevent others from denying you these rights or asking you to surrender the rights. Therefore, you have certain responsibilities if you distribute copies of the software, or if you modify it: responsibilities to respect the freedom of others.

For example, if you distribute copies of such a program, whether gratis or for a fee, you must pass on to the recipients the same freedoms that you received. 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.

Developers that use the GNU GPL protect your rights with two steps: (1) assert copyright on the software, and (2) offer you this License giving you legal permission to copy, distribute and/or modify it.

For the developers' and authors' protection, the GPL clearly explains that there is no warranty for this free software. For both users' and authors' sake, the GPL requires that modified versions be marked as changed, so that their problems will not be attributed erroneously to authors of previous versions.

Some devices are designed to deny users access to install or run modified versions of the software inside them, although the manufacturer can do so. This is fundamentally incompatible with the aim of protecting users' freedom to change the software. The systematic pattern of such abuse occurs in the area of products for individuals to use, which is precisely where it is most unacceptable. Therefore, we have designed this version of the GPL to prohibit the practice for those products. If such problems arise substantially in other

domains, we stand ready to extend this provision to those domains in future versions of the GPL, as needed to protect the freedom of users.

Finally, every program is threatened constantly by software patents. States should not allow patents to restrict development and use of software on general-purpose computers, but in those that do, we wish to avoid the special danger that patents applied to a free program could make it effectively proprietary. To prevent this, the GPL assures that patents cannot be used to render the program non-free.

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

## TERMS AND CONDITIONS

### 0. Definitions.

“This License” refers to version 3 of the GNU General Public License.

“Copyright” also means copyright-like laws that apply to other kinds of works, such as semiconductor masks.

“The Program” refers to any copyrightable work licensed under this License. Each licensee is addressed as “you”. “Licensees” and “recipients” may be individuals or organizations.

To “modify” a work means to copy from or adapt all or part of the work in a fashion requiring copyright permission, other than the making of an exact copy. The resulting work is called a “modified version” of the earlier work or a work “based on” the earlier work.

A “covered work” means either the unmodified Program or a work based on the Program.

To “propagate” a work means to do anything with it that, without permission, would make you directly or secondarily liable for infringement under applicable copyright law, except executing it on a computer or modifying a private copy. Propagation includes copying, distribution (with or without modification), making available to the public, and in some countries other activities as well.

To “convey” a work means any kind of propagation that enables other parties to make or receive copies. Mere interaction with a user through a computer network, with no transfer of a copy, is not conveying.

An interactive user interface displays “Appropriate Legal Notices” to the extent that it includes a convenient and prominently visible feature that (1) displays an appropriate copyright notice, and (2) tells the user that there is no warranty for the work (except to the extent that warranties are provided), that licensees may convey the work under this License, and how to view a copy of this License. If the interface presents a list of user commands or options, such as a menu, a prominent item in the list meets this criterion.

### 1. Source Code.

The “source code” for a work means the preferred form of the work for making modifications to it. “Object code” means any non-source form of a work.

A “Standard Interface” means an interface that either is an official standard defined by a recognized standards body, or, in the case of interfaces specified for a particular

programming language, one that is widely used among developers working in that language.

The “System Libraries” of an executable work include anything, other than the work as a whole, that (a) is included in the normal form of packaging a Major Component, but which is not part of that Major Component, and (b) serves only to enable use of the work with that Major Component, or to implement a Standard Interface for which an implementation is available to the public in source code form. A “Major Component”, in this context, means a major essential component (kernel, window system, and so on) of the specific operating system (if any) on which the executable work runs, or a compiler used to produce the work, or an object code interpreter used to run it.

The “Corresponding Source” for a work in object code form means all the source code needed to generate, install, and (for an executable work) run the object code and to modify the work, including scripts to control those activities. However, it does not include the work’s System Libraries, or general-purpose tools or generally available free programs which are used unmodified in performing those activities but which are not part of the work. For example, Corresponding Source includes interface definition files associated with source files for the work, and the source code for shared libraries and dynamically linked subprograms that the work is specifically designed to require, such as by intimate data communication or control flow between those subprograms and other parts of the work.

The Corresponding Source need not include anything that users can regenerate automatically from other parts of the Corresponding Source.

The Corresponding Source for a work in source code form is that same work.

## 2. Basic Permissions.

All rights granted under this License are granted for the term of copyright on the Program, and are irrevocable provided the stated conditions are met. This License explicitly affirms your unlimited permission to run the unmodified Program. The output from running a covered work is covered by this License only if the output, given its content, constitutes a covered work. This License acknowledges your rights of fair use or other equivalent, as provided by copyright law.

You may make, run and propagate covered works that you do not convey, without conditions so long as your license otherwise remains in force. You may convey covered works to others for the sole purpose of having them make modifications exclusively for you, or provide you with facilities for running those works, provided that you comply with the terms of this License in conveying all material for which you do not control copyright. Those thus making or running the covered works for you must do so exclusively on your behalf, under your direction and control, on terms that prohibit them from making any copies of your copyrighted material outside their relationship with you.

Conveying under any other circumstances is permitted solely under the conditions stated below. Sublicensing is not allowed; section 10 makes it unnecessary.

## 3. Protecting Users’ Legal Rights From Anti-Circumvention Law.

No covered work shall be deemed part of an effective technological measure under any applicable law fulfilling obligations under article 11 of the WIPO copyright treaty



adopted on 20 December 1996, or similar laws prohibiting or restricting circumvention of such measures.

When you convey a covered work, you waive any legal power to forbid circumvention of technological measures to the extent such circumvention is effected by exercising rights under this License with respect to the covered work, and you disclaim any intention to limit operation or modification of the work as a means of enforcing, against the work's users, your or third parties' legal rights to forbid circumvention of technological measures.

#### 4. Conveying Verbatim Copies.

You may convey 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; keep intact all notices stating that this License and any non-permissive terms added in accord with section 7 apply to the code; keep intact all notices of the absence of any warranty; and give all recipients a copy of this License along with the Program.

You may charge any price or no price for each copy that you convey, and you may offer support or warranty protection for a fee.

#### 5. Conveying Modified Source Versions.

You may convey a work based on the Program, or the modifications to produce it from the Program, in the form of source code under the terms of section 4, provided that you also meet all of these conditions:

- a. The work must carry prominent notices stating that you modified it, and giving a relevant date.
- b. The work must carry prominent notices stating that it is released under this License and any conditions added under section 7. This requirement modifies the requirement in section 4 to "keep intact all notices".
- c. You must license the entire work, as a whole, under this License to anyone who comes into possession of a copy. This License will therefore apply, along with any applicable section 7 additional terms, to the whole of the work, and all its parts, regardless of how they are packaged. This License gives no permission to license the work in any other way, but it does not invalidate such permission if you have separately received it.
- d. If the work has interactive user interfaces, each must display Appropriate Legal Notices; however, if the Program has interactive interfaces that do not display Appropriate Legal Notices, your work need not make them do so.

A compilation of a covered work with other separate and independent works, which are not by their nature extensions of the covered work, and which are not combined with it such as to form a larger program, in or on a volume of a storage or distribution medium, is called an "aggregate" if the compilation and its resulting copyright are not used to limit the access or legal rights of the compilation's users beyond what the individual works permit. Inclusion of a covered work in an aggregate does not cause this License to apply to the other parts of the aggregate.

#### 6. Conveying Non-Source Forms.

You may convey a covered work in object code form under the terms of sections 4 and 5, provided that you also convey the machine-readable Corresponding Source under the terms of this License, in one of these ways:

- a. Convey the object code in, or embodied in, a physical product (including a physical distribution medium), accompanied by the Corresponding Source fixed on a durable physical medium customarily used for software interchange.
- b. Convey the object code in, or embodied in, a physical product (including a physical distribution medium), accompanied by a written offer, valid for at least three years and valid for as long as you offer spare parts or customer support for that product model, to give anyone who possesses the object code either (1) a copy of the Corresponding Source for all the software in the product that is covered by this License, on a durable physical medium customarily used for software interchange, for a price no more than your reasonable cost of physically performing this conveying of source, or (2) access to copy the Corresponding Source from a network server at no charge.
- c. Convey individual copies of the object code with a copy of the written offer to provide the Corresponding Source. This alternative is allowed only occasionally and noncommercially, and only if you received the object code with such an offer, in accord with subsection 6b.
- d. Convey the object code by offering access from a designated place (gratis or for a charge), and offer equivalent access to the Corresponding Source in the same way through the same place at no further charge. You need not require recipients to copy the Corresponding Source along with the object code. If the place to copy the object code is a network server, the Corresponding Source may be on a different server (operated by you or a third party) that supports equivalent copying facilities, provided you maintain clear directions next to the object code saying where to find the Corresponding Source. Regardless of what server hosts the Corresponding Source, you remain obligated to ensure that it is available for as long as needed to satisfy these requirements.
- e. Convey the object code using peer-to-peer transmission, provided you inform other peers where the object code and Corresponding Source of the work are being offered to the general public at no charge under subsection 6d.

A separable portion of the object code, whose source code is excluded from the Corresponding Source as a System Library, need not be included in conveying the object code work.

A “User Product” is either (1) a “consumer product”, which means any tangible personal property which is normally used for personal, family, or household purposes, or (2) anything designed or sold for incorporation into a dwelling. In determining whether a product is a consumer product, doubtful cases shall be resolved in favor of coverage. For a particular product received by a particular user, “normally used” refers to a typical or common use of that class of product, regardless of the status of the particular user or of the way in which the particular user actually uses, or expects or is expected to use, the product. A product is a consumer product regardless of whether the product has substantial commercial, industrial or non-consumer uses, unless such uses represent the only significant mode of use of the product.

“Installation Information” for a User Product means any methods, procedures, authorization keys, or other information required to install and execute modified versions of a covered work in that User Product from a modified version of its Corresponding Source. The information must suffice to ensure that the continued functioning of the modified object code is in no case prevented or interfered with solely because modification has been made.

If you convey an object code work under this section in, or with, or specifically for use in, a User Product, and the conveying occurs as part of a transaction in which the right of possession and use of the User Product is transferred to the recipient in perpetuity or for a fixed term (regardless of how the transaction is characterized), the Corresponding Source conveyed under this section must be accompanied by the Installation Information. But this requirement does not apply if neither you nor any third party retains the ability to install modified object code on the User Product (for example, the work has been installed in ROM).

The requirement to provide Installation Information does not include a requirement to continue to provide support service, warranty, or updates for a work that has been modified or installed by the recipient, or for the User Product in which it has been modified or installed. Access to a network may be denied when the modification itself materially and adversely affects the operation of the network or violates the rules and protocols for communication across the network.

Corresponding Source conveyed, and Installation Information provided, in accord with this section must be in a format that is publicly documented (and with an implementation available to the public in source code form), and must require no special password or key for unpacking, reading or copying.

## 7. Additional Terms.

“Additional permissions” are terms that supplement the terms of this License by making exceptions from one or more of its conditions. Additional permissions that are applicable to the entire Program shall be treated as though they were included in this License, to the extent that they are valid under applicable law. If additional permissions apply only to part of the Program, that part may be used separately under those permissions, but the entire Program remains governed by this License without regard to the additional permissions.

When you convey a copy of a covered work, you may at your option remove any additional permissions from that copy, or from any part of it. (Additional permissions may be written to require their own removal in certain cases when you modify the work.) You may place additional permissions on material, added by you to a covered work, for which you have or can give appropriate copyright permission.

Notwithstanding any other provision of this License, for material you add to a covered work, you may (if authorized by the copyright holders of that material) supplement the terms of this License with terms:

- a. Disclaiming warranty or limiting liability differently from the terms of sections 15 and 16 of this License; or
- b. Requiring preservation of specified reasonable legal notices or author attributions in that material or in the Appropriate Legal Notices displayed by works containing it; or

- c. Prohibiting misrepresentation of the origin of that material, or requiring that modified versions of such material be marked in reasonable ways as different from the original version; or
- d. Limiting the use for publicity purposes of names of licensors or authors of the material; or
- e. Declining to grant rights under trademark law for use of some trade names, trademarks, or service marks; or
- f. Requiring indemnification of licensors and authors of that material by anyone who conveys the material (or modified versions of it) with contractual assumptions of liability to the recipient, for any liability that these contractual assumptions directly impose on those licensors and authors.

All other non-permissive additional terms are considered “further restrictions” within the meaning of section 10. If the Program as you received it, or any part of it, contains a notice stating that it is governed by this License along with a term that is a further restriction, you may remove that term. If a license document contains a further restriction but permits relicensing or conveying under this License, you may add to a covered work material governed by the terms of that license document, provided that the further restriction does not survive such relicensing or conveying.

If you add terms to a covered work in accord with this section, you must place, in the relevant source files, a statement of the additional terms that apply to those files, or a notice indicating where to find the applicable terms.

Additional terms, permissive or non-permissive, may be stated in the form of a separately written license, or stated as exceptions; the above requirements apply either way.

## 8. Termination.

You may not propagate or modify a covered work except as expressly provided under this License. Any attempt otherwise to propagate or modify it is void, and will automatically terminate your rights under this License (including any patent licenses granted under the third paragraph of section 11).

However, if you cease all violation of this License, then your license from a particular copyright holder is reinstated (a) provisionally, unless and until the copyright holder explicitly and finally terminates your license, and (b) permanently, if the copyright holder fails to notify you of the violation by some reasonable means prior to 60 days after the cessation.

Moreover, your license from a particular copyright holder is reinstated permanently if the copyright holder notifies you of the violation by some reasonable means, this is the first time you have received notice of violation of this License (for any work) from that copyright holder, and you cure the violation prior to 30 days after your receipt of the notice.

Termination of your rights under this section does not terminate the licenses of parties who have received copies or rights from you under this License. If your rights have been terminated and not permanently reinstated, you do not qualify to receive new licenses for the same material under section 10.

9. Acceptance Not Required for Having Copies.

You are not required to accept this License in order to receive or run a copy of the Program. Ancillary propagation of a covered work occurring solely as a consequence of using peer-to-peer transmission to receive a copy likewise does not require acceptance. However, nothing other than this License grants you permission to propagate or modify any covered work. These actions infringe copyright if you do not accept this License. Therefore, by modifying or propagating a covered work, you indicate your acceptance of this License to do so.

10. Automatic Licensing of Downstream Recipients.

Each time you convey a covered work, the recipient automatically receives a license from the original licensors, to run, modify and propagate that work, subject to this License. You are not responsible for enforcing compliance by third parties with this License.

An “entity transaction” is a transaction transferring control of an organization, or substantially all assets of one, or subdividing an organization, or merging organizations. If propagation of a covered work results from an entity transaction, each party to that transaction who receives a copy of the work also receives whatever licenses to the work the party’s predecessor in interest had or could give under the previous paragraph, plus a right to possession of the Corresponding Source of the work from the predecessor in interest, if the predecessor has it or can get it with reasonable efforts.

You may not impose any further restrictions on the exercise of the rights granted or affirmed under this License. For example, you may not impose a license fee, royalty, or other charge for exercise of rights granted under this License, and you may not initiate litigation (including a cross-claim or counterclaim in a lawsuit) alleging that any patent claim is infringed by making, using, selling, offering for sale, or importing the Program or any portion of it.

11. Patents.

A “contributor” is a copyright holder who authorizes use under this License of the Program or a work on which the Program is based. The work thus licensed is called the contributor’s “contributor version”.

A contributor’s “essential patent claims” are all patent claims owned or controlled by the contributor, whether already acquired or hereafter acquired, that would be infringed by some manner, permitted by this License, of making, using, or selling its contributor version, but do not include claims that would be infringed only as a consequence of further modification of the contributor version. For purposes of this definition, “control” includes the right to grant patent sublicenses in a manner consistent with the requirements of this License.

Each contributor grants you a non-exclusive, worldwide, royalty-free patent license under the contributor’s essential patent claims, to make, use, sell, offer for sale, import and otherwise run, modify and propagate the contents of its contributor version.

In the following three paragraphs, a “patent license” is any express agreement or commitment, however denominated, not to enforce a patent (such as an express permission to practice a patent or covenant not to sue for patent infringement). To “grant” such a patent license to a party means to make such an agreement or commitment not to enforce a patent against the party.

If you convey a covered work, knowingly relying on a patent license, and the Corresponding Source of the work is not available for anyone to copy, free of charge and under the terms of this License, through a publicly available network server or other readily accessible means, then you must either (1) cause the Corresponding Source to be so available, or (2) arrange to deprive yourself of the benefit of the patent license for this particular work, or (3) arrange, in a manner consistent with the requirements of this License, to extend the patent license to downstream recipients. “Knowingly relying” means you have actual knowledge that, but for the patent license, your conveying the covered work in a country, or your recipient’s use of the covered work in a country, would infringe one or more identifiable patents in that country that you have reason to believe are valid.

If, pursuant to or in connection with a single transaction or arrangement, you convey, or propagate by procuring conveyance of, a covered work, and grant a patent license to some of the parties receiving the covered work authorizing them to use, propagate, modify or convey a specific copy of the covered work, then the patent license you grant is automatically extended to all recipients of the covered work and works based on it.

A patent license is “discriminatory” if it does not include within the scope of its coverage, prohibits the exercise of, or is conditioned on the non-exercise of one or more of the rights that are specifically granted under this License. You may not convey a covered work if you are a party to an arrangement with a third party that is in the business of distributing software, under which you make payment to the third party based on the extent of your activity of conveying the work, and under which the third party grants, to any of the parties who would receive the covered work from you, a discriminatory patent license (a) in connection with copies of the covered work conveyed by you (or copies made from those copies), or (b) primarily for and in connection with specific products or compilations that contain the covered work, unless you entered into that arrangement, or that patent license was granted, prior to 28 March 2007.

Nothing in this License shall be construed as excluding or limiting any implied license or other defenses to infringement that may otherwise be available to you under applicable patent law.

12. No Surrender of Others’ Freedom.

If 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 convey a covered work so as to satisfy simultaneously your obligations under this License and any other pertinent obligations, then as a consequence you may not convey it at all. For example, if you agree to terms that obligate you to collect a royalty for further conveying from those to whom you convey the Program, the only way you could satisfy both those terms and this License would be to refrain entirely from conveying the Program.

13. Use with the GNU Affero General Public License.

Notwithstanding any other provision of this License, you have permission to link or combine any covered work with a work licensed under version 3 of the GNU Affero General Public License into a single combined work, and to convey the resulting work. The terms of this License will continue to apply to the part which is the covered work,

but the special requirements of the GNU Affero General Public License, section 13, concerning interaction through a network will apply to the combination as such.

14. Revised Versions of this License.

The Free Software Foundation may publish revised and/or new versions of the GNU 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 that a certain numbered version of the GNU General Public License “or any later version” applies to it, you have the option of following the terms and conditions either of that numbered version or of any later version published by the Free Software Foundation. If the Program does not specify a version number of the GNU General Public License, you may choose any version ever published by the Free Software Foundation.

If the Program specifies that a proxy can decide which future versions of the GNU General Public License can be used, that proxy’s public statement of acceptance of a version permanently authorizes you to choose that version for the Program.

Later license versions may give you additional or different permissions. However, no additional obligations are imposed on any author or copyright holder as a result of your choosing to follow a later version.

15. Disclaimer of Warranty.

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.

16. Limitation of Liability.

IN NO EVENT UNLESS REQUIRED BY APPLICABLE LAW OR AGREED TO IN WRITING WILL ANY COPYRIGHT HOLDER, OR ANY OTHER PARTY WHO MODIFIES AND/OR CONVEYS 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.

17. Interpretation of Sections 15 and 16.

If the disclaimer of warranty and limitation of liability provided above cannot be given local legal effect according to their terms, reviewing courts shall apply local law that most closely approximates an absolute waiver of all civil liability in connection with

the Program, unless a warranty or assumption of liability accompanies a copy of the Program in return for a fee.

## END OF TERMS AND CONDITIONS

### 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 state 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) year 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 3 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, see https://www.gnu.org/licenses/.
```

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

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

```
program Copyright (C) year name of author
This program 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 hypothetical commands ‘show w’ and ‘show c’ should show the appropriate parts of the General Public License. Of course, your program’s commands might be different; for a GUI interface, you would use an “about box”.

You should also get your employer (if you work as a programmer) or school, if any, to sign a “copyright disclaimer” for the program, if necessary. For more information on this, and how to apply and follow the GNU GPL, see <https://www.gnu.org/licenses/>.

The GNU 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 Lesser General Public License instead of this License. But first, please read <https://www.gnu.org/licenses/why-not-lgpl.html>.



## 2 A Brief Introduction to Octave

This manual documents how to run, install and port Octave's C++ classes, and how to report bugs.

## 3 Arrays

### 3.1 Constructors and Assignment

`Array<T> (void)` [Constructor]  
Create an array with no elements.

`Array<T> (int n [, const T &val])` [Constructor]  
Create an array with  $n$  elements. If the optional argument *val* is supplied, the elements are initialized to *val*; otherwise, they are left uninitialized. If  $n$  is less than zero, the current error handler is invoked (see Chapter 13 [Error Handling], page 47).

`Array<T> (const Array<T> &a)` [Constructor]  
Create a copy of the `Array<T>` object *a*. Memory for the `Array<T>` class is managed using a reference counting scheme, so the cost of this operation is independent of the size of the array.

`Array<T>& operator = (const Array<T> &a)` [Assignment on Array<T>]  
Assignment operator. Memory for the `Array<T>` class is managed using a reference counting scheme, so the cost of this operation is independent of the size of the array.

`int capacity (void) const` [Method on Array<T>]  
`int length (void) const` [Method on Array<T>]  
Return the length of the array.

`T& elem (int n)` [Method on Array<T>]  
`T& checkelem (int n)` [Method on Array<T>]  
If  $n$  is within the bounds of the array, return a reference to the element indexed by  $n$ ; otherwise, the current error handler is invoked (see Chapter 13 [Error Handling], page 47).

`T& operator () (int n)` [Indexing on Array<T>]  
`T elem (int n) const` [Method on Array<T>]  
`T checkelem (int n) const` [Method on Array<T>]  
If  $n$  is within the bounds of the array, return the value indexed by  $n$ ; otherwise, call the current error handler. See Chapter 13 [Error Handling], page 47.

`T operator () (int n) const` [Indexing on Array<T>]  
`T& xelem (int n)` [Method on Array<T>]  
`T xelem (int n) const` [Method on Array<T>]  
Return a reference to, or the value of, the element indexed by  $n$ . These methods never perform bounds checking.

`void resize (int n [, const T &val])` [Method on Array<T>]  
Change the size of the array to be  $n$  elements. All elements are unchanged, except that if  $n$  is greater than the current size and the optional argument *val* is provided,

the additional elements are initialized to *val*; otherwise, any additional elements are left uninitialized. In the current implementation, if *n* is less than the current size, the length is updated but no memory is released.

<code>const T* data (void) const</code>	[Method on <code>Array&lt;T&gt;</code> ]
<code>Array2&lt;T&gt; Array2&lt;T&gt; Array2 (void)</code>	[Constructor]
<code>Array2&lt;T&gt; (int n, int m)</code>	[Constructor]
<code>Array2&lt;T&gt; (int n, int m, const T &amp;val)</code>	[Constructor]
<code>Array2&lt;T&gt; (const Array2&lt;T&gt; &amp;a)</code>	[Constructor]
<code>Array2&lt;T&gt; (const DiagArray&lt;T&gt; &amp;a)</code>	[Constructor]
<code>Array2&lt;T&gt;&amp; operator = (const Array2&lt;T&gt; &amp;a)</code>	[Assignment on <code>Array2&lt;T&gt;</code> ]
<code>int dim1 (void) const</code>	[Method on <code>Array2&lt;T&gt;</code> ]
<code>int rows (void) const</code>	[Method on <code>Array2&lt;T&gt;</code> ]
<code>int dim2 (void) const</code>	[Method on <code>Array2&lt;T&gt;</code> ]
<code>int cols (void) const</code>	[Method on <code>Array2&lt;T&gt;</code> ]
<code>int columns (void) const</code>	[Method on <code>Array2&lt;T&gt;</code> ]
<code>T&amp; elem (int i, int j)</code>	[Method on <code>Array2&lt;T&gt;</code> ]
<code>T&amp; checkelem (int i, int j)</code>	[Method on <code>Array2&lt;T&gt;</code> ]
<code>T&amp; operator () (int i, int j)</code>	[Indexing on <code>Array2&lt;T&gt;</code> ]
<code>void resize (int n, int m)</code>	[Method on <code>Array2&lt;T&gt;</code> ]
<code>void resize (int n, int m, const T &amp;val)</code>	[Method on <code>Array2&lt;T&gt;</code> ]
<code>Array3&lt;T&gt; (void)</code>	[Constructor]
<code>Array3&lt;T&gt; (int n, int m, int k)</code>	[Constructor]
<code>Array3&lt;T&gt; (int n, int m, int k, const T &amp;val)</code>	[Constructor]
<code>Array3&lt;T&gt; (const Array3&lt;T&gt; &amp;a)</code>	[Constructor]
<code>Array3&lt;T&gt;&amp; operator = (const Array3&lt;T&gt; &amp;a)</code>	[Assignment on <code>Array3&lt;T&gt;</code> ]
<code>int dim1 (void) const</code>	[Method on <code>Array3&lt;T&gt;</code> ]
<code>int dim2 (void) const</code>	[Method on <code>Array3&lt;T&gt;</code> ]
<code>int dim3 (void) const</code>	[Method on <code>Array3&lt;T&gt;</code> ]
<code>T&amp; elem (int i, int j, int k)</code>	[Method on <code>Array3&lt;T&gt;</code> ]
<code>T&amp; checkelem (int i, int j, int k)</code>	[Method on <code>Array3&lt;T&gt;</code> ]
<code>T&amp; operator () (int i, int j, int k)</code>	[Indexing on <code>Array3&lt;T&gt;</code> ]
<code>void resize (int n, int m, int k)</code>	[Method on <code>Array3&lt;T&gt;</code> ]
<code>void resize (int n, int m, int k, const T &amp;val)</code>	[Method on <code>Array3&lt;T&gt;</code> ]
<code>DiagArray&lt;T&gt; (void)</code>	[Constructor]
<code>DiagArray&lt;T&gt; (int n)</code>	[Constructor]
<code>DiagArray&lt;T&gt; (int n, const T &amp;val)</code>	[Constructor]
<code>DiagArray&lt;T&gt; (int r, int c)</code>	[Constructor]
<code>DiagArray&lt;T&gt; (int r, int c, const T &amp;val)</code>	[Constructor]
<code>DiagArray&lt;T&gt; (const Array&lt;T&gt; &amp;a)</code>	[Constructor]
<code>DiagArray&lt;T&gt; (const DiagArray&lt;T&gt; &amp;a)</code>	[Constructor]
<code>operator = (const DiagArray&lt;T&gt; &amp;a)</code>	[Assignment on <code>DiagArray&lt;T&gt;&amp;</code> ]

<code>int dim1 (void) const</code>	[Method on <code>DiagArray&lt;T&gt;</code> ]
<code>int rows (void) const</code>	[Method on <code>DiagArray&lt;T&gt;</code> ]
<code>int dim2 (void) const</code>	[Method on <code>DiagArray&lt;T&gt;</code> ]
<code>int cols (void) const</code>	[Method on <code>DiagArray&lt;T&gt;</code> ]
<code>int columns (void) const</code>	[Method on <code>DiagArray&lt;T&gt;</code> ]
<code>T&amp; elem (int r, int c)</code>	[Method on <code>DiagArray&lt;T&gt;</code> ]
<code>T&amp; checkelem (int r, int c)</code>	[Method on <code>DiagArray&lt;T&gt;</code> ]
<code>T&amp; operator () (int r, int c)</code>	[Indexing on <code>DiagArray&lt;T&gt;</code> ]
<code>void resize (int n, int m)</code>	[Method on <code>DiagArray&lt;T&gt;</code> ]
<code>void resize (int n, int m, const T &amp;val)</code>	[Method on <code>DiagArray&lt;T&gt;</code> ]

The real and complex `ColumnVector` and `RowVector` classes all have the following functions. These will eventually be part of an `MArray<T>` class, derived from the `Array<T>` class. Then the `ColumnVector` and `RowVector` classes will be derived from the `MArray<T>` class.

Element by element vector by scalar ops.

```
RowVector operator + (const RowVector &a, const double &s)
RowVector operator - (const RowVector &a, const double &s)
RowVector operator * (const RowVector &a, const double &s)
RowVector operator / (const RowVector &a, const double &s)
```

Element by element scalar by vector ops.

```
RowVector operator + (const double &s, const RowVector &a)
RowVector operator - (const double &s, const RowVector &a)
RowVector operator * (const double &s, const RowVector &a)
RowVector operator / (const double &s, const RowVector &a)
```

Element by element vector by vector ops.

```
RowVector operator + (const RowVector &a, const RowVector &b)
RowVector operator - (const RowVector &a, const RowVector &b)

RowVector product (const RowVector &a, const RowVector &b)
RowVector quotient (const RowVector &a, const RowVector &b)
```

Unary `MArray` ops.

```
RowVector operator - (const RowVector &a)
```

The `Matrix` classes share the following functions. These will eventually be part of an `MArray2<T>` class, derived from the `Array2<T>` class. Then the `Matrix` class will be derived from the `MArray<T>` class.

Element by element matrix by scalar ops.

```
Matrix operator + (const Matrix &a, const double &s)
Matrix operator - (const Matrix &a, const double &s)
Matrix operator * (const Matrix &a, const double &s)
Matrix operator / (const Matrix &a, const double &s)
```

Element by element scalar by matrix ops.

`Matrix operator + (const double &s, const Matrix &a)`  
`Matrix operator - (const double &s, const Matrix &a)`  
`Matrix operator * (const double &s, const Matrix &a)`  
`Matrix operator / (const double &s, const Matrix &a)`

Element by element matrix by matrix ops.

`Matrix operator + (const Matrix &a, const Matrix &b)`  
`Matrix operator - (const Matrix &a, const Matrix &b)`

`Matrix product (const Matrix &a, const Matrix &b)`  
`Matrix quotient (const Matrix &a, const Matrix &b)`

Unary matrix ops.

`Matrix operator - (const Matrix &a)`

The `DiagMatrix` classes share the following functions. These will eventually be part of an `MDiagArray<T>` class, derived from the `DiagArray<T>` class. Then the `DiagMatrix` class will be derived from the `MDiagArray<T>` class.

Element by element `MDiagArray` by scalar ops.

`DiagMatrix operator * (const DiagMatrix &a, const double &s)`  
`DiagMatrix operator / (const DiagMatrix &a, const double &s)`

Element by element scalar by `MDiagArray` ops.

`DiagMatrix operator * (const double &s, const DiagMatrix &a)`

Element by element `MDiagArray` by `MDiagArray` ops.

`DiagMatrix operator + (const DiagMatrix &a, const DiagMatrix &b)`  
`DiagMatrix operator - (const DiagMatrix &a, const DiagMatrix &b)`

`DiagMatrix product (const DiagMatrix &a, const DiagMatrix &b)`

Unary `MDiagArray` ops.

`DiagMatrix operator - (const DiagMatrix &a)`

## 4 Matrix and Vector Operations

```

Matrix (void)
Matrix (int r, int c)
Matrix (int r, int c, double val)
Matrix (const Array2<double> &a)
Matrix (const Matrix &a)
Matrix (const DiagArray<double> &a)
Matrix (const DiagMatrix &a)

Matrix& operator = (const Matrix &a)

int operator == (const Matrix &a) const
int operator != (const Matrix &a) const

Matrix& insert (const Matrix &a, int r, int c)
Matrix& insert (const RowVector &a, int r, int c)
Matrix& insert (const ColumnVector &a, int r, int c)
Matrix& insert (const DiagMatrix &a, int r, int c)

Matrix& fill (double val)
Matrix& fill (double val, int r1, int c1, int r2, int c2)

Matrix append (const Matrix &a) const
Matrix append (const RowVector &a) const
Matrix append (const ColumnVector &a) const
Matrix append (const DiagMatrix &a) const

Matrix stack (const Matrix &a) const
Matrix stack (const RowVector &a) const
Matrix stack (const ColumnVector &a) const
Matrix stack (const DiagMatrix &a) const

Matrix transpose (void) const

Matrix extract (int r1, int c1, int r2, int c2) const

RowVector row (int i) const
RowVector row (char *s) const

ColumnVector column (int i) const
ColumnVector column (char *s) const

Matrix inverse (void) const
Matrix inverse (int &info) const
Matrix inverse (int &info, double &rcond) const

ComplexMatrix fourier (void) const
ComplexMatrix ifourier (void) const

DET determinant (void) const
DET determinant (int &info) const
DET determinant (int &info, double &rcond) const

Matrix solve (const Matrix &b) const

```

```

Matrix solve (const Matrix &b, int &info) const
Matrix solve (const Matrix &b, int &info, double &rcond) const

ComplexMatrix solve (const ComplexMatrix &b) const
ComplexMatrix solve (const ComplexMatrix &b, int &info) const
ComplexMatrix solve (const ComplexMatrix &b, int &info, double &rcond)
    const

ColumnVector solve (const ColumnVector &b) const
ColumnVector solve (const ColumnVector &b, int &info) const
ColumnVector solve (const ColumnVector &b, int &info, double &rcond)
    const

ComplexColumnVector solve (const ComplexColumnVector &b) const
ComplexColumnVector solve (const ComplexColumnVector &b, int &info)
    const
ComplexColumnVector solve (const ComplexColumnVector &b, int &info,
    double &rcond) const

Matrix lssolve (const Matrix &b) const
Matrix lssolve (const Matrix &b, int &info) const
Matrix lssolve (const Matrix &b, int &info, int &rank) const

ComplexMatrix lssolve (const ComplexMatrix &b) const
ComplexMatrix lssolve (const ComplexMatrix &b, int &info) const
ComplexMatrix lssolve (const ComplexMatrix &b, int &info, int &rank)
    const

ColumnVector lssolve (const ColumnVector &b) const
ColumnVector lssolve (const ColumnVector &b, int &info) const
ColumnVector lssolve (const ColumnVector &b, int &info, int &rank) const

ComplexColumnVector lssolve (const ComplexColumnVector &b) const
ComplexColumnVector lssolve (const ComplexColumnVector &b, int
    &info) const
ComplexColumnVector lssolve (const ComplexColumnVector &b, int &info,
    int &rank) const

Matrix& operator += (const Matrix &a)
Matrix& operator -= (const Matrix &a)

Matrix& operator += (const DiagMatrix &a)
Matrix& operator -= (const DiagMatrix &a)

Matrix operator ! (void) const

ComplexMatrix operator + (const Matrix &a, const Complex &s)
ComplexMatrix operator - (const Matrix &a, const Complex &s)
ComplexMatrix operator * (const Matrix &a, const Complex &s)
ComplexMatrix operator / (const Matrix &a, const Complex &s)

ComplexMatrix operator + (const Complex &s, const Matrix &a)
ComplexMatrix operator - (const Complex &s, const Matrix &a)
ComplexMatrix operator * (const Complex &s, const Matrix &a)

```

```

ComplexMatrix operator / (const Complex &s, const Matrix &a)
ColumnVector operator * (const Matrix &a, const ColumnVector &b)
ComplexColumnVector operator * (const Matrix &a, const
    ComplexColumnVector &b)

Matrix operator + (const Matrix &a, const DiagMatrix &b)
Matrix operator - (const Matrix &a, const DiagMatrix &b)
Matrix operator * (const Matrix &a, const DiagMatrix &b)

ComplexMatrix operator + (const Matrix &a, const ComplexDiagMatrix &b)
ComplexMatrix operator - (const Matrix &a, const ComplexDiagMatrix &b)
ComplexMatrix operator * (const Matrix &a, const ComplexDiagMatrix &b)

Matrix operator * (const Matrix &a, const Matrix &b)
ComplexMatrix operator * (const Matrix &a, const ComplexMatrix &b)

ComplexMatrix operator + (const Matrix &a, const ComplexMatrix &b)
ComplexMatrix operator - (const Matrix &a, const ComplexMatrix &b)

ComplexMatrix product (const Matrix &a, const ComplexMatrix &b)
ComplexMatrix quotient (const Matrix &a, const ComplexMatrix &b)

Matrix map (d_d_Mapper f, const Matrix &a)
void map (d_d_Mapper f)

Matrix all (void) const
Matrix any (void) const

Matrix cumprod (void) const
Matrix cumsum (void) const
Matrix prod (void) const
Matrix sum (void) const
Matrix sumsq (void) const

ColumnVector diag (void) const
ColumnVector diag (int k) const

ColumnVector row_min (void) const
ColumnVector row_min_loc (void) const

ColumnVector row_max (void) const
ColumnVector row_max_loc (void) const

RowVector column_min (void) const
RowVector column_min_loc (void) const

RowVector column_max (void) const
RowVector column_max_loc (void) const

ostream& operator << (ostream &os, const Matrix &a)
istream& operator >> (istream &is, Matrix &a)

ColumnVector (void)
ColumnVector (int n)
ColumnVector (int n, double val)

```



```

ColumnVector (const Array<double> &a)
ColumnVector (const ColumnVector &a)
ColumnVector& operator = (const ColumnVector &a)
int operator == (const ColumnVector &a) const
int operator != (const ColumnVector &a) const
ColumnVector& insert (const ColumnVector &a, int r)
ColumnVector& fill (double val)
ColumnVector& fill (double val, int r1, int r2)
ColumnVector stack (const ColumnVector &a) const
RowVector transpose (void) const
ColumnVector extract (int r1, int r2) const
ColumnVector& operator += (const ColumnVector &a)
ColumnVector& operator -= (const ColumnVector &a)
ComplexColumnVector operator + (const ColumnVector &a, const Complex
                                &s)
ComplexColumnVector operator - (const ColumnVector &a, const Complex
                                &s)
ComplexColumnVector operator * (const ColumnVector &a, const Complex
                                &s)
ComplexColumnVector operator / (const ColumnVector &a, const Complex
                                &s)
ComplexColumnVector operator + (const Complex &s, const ColumnVector
                                &a)
ComplexColumnVector operator - (const Complex &s, const ColumnVector
                                &a)
ComplexColumnVector operator * (const Complex &s, const ColumnVector
                                &a)
ComplexColumnVector operator / (const Complex &s, const ColumnVector
                                &a)
Matrix operator * (const ColumnVector &a, const RowVector &a)
ComplexMatrix operator * (const ColumnVector &a, const
                          ComplexRowVector &b)
ComplexColumnVector operator + (const ComplexColumnVector &a, const
                                ComplexColumnVector &b)
ComplexColumnVector operator - (const ComplexColumnVector &a, const
                                ComplexColumnVector &b)
ComplexColumnVector product (const ComplexColumnVector &a, const
                              ComplexColumnVector &b)
ComplexColumnVector quotient (const ComplexColumnVector &a, const
                              ComplexColumnVector &b)
ColumnVector map (d_d_Mapper f, const ColumnVector &a)

```

```

void map (d_d_Mapper f)
double min (void) const
double max (void) const
ostream& operator << (ostream &os, const ColumnVector &a)

RowVector (void)
RowVector (int n)
RowVector (int n, double val)
RowVector (const Array<double> &a)
RowVector (const RowVector &a)

RowVector& operator = (const RowVector &a)
int operator == (const RowVector &a) const
int operator != (const RowVector &a) const
RowVector& insert (const RowVector &a, int c)
RowVector& fill (double val)
RowVector& fill (double val, int c1, int c2)
RowVector append (const RowVector &a) const
ColumnVector transpose (void) const
RowVector extract (int c1, int c2) const
RowVector& operator += (const RowVector &a)
RowVector& operator -= (const RowVector &a)

ComplexRowVector operator + (const RowVector &a, const Complex &s)
ComplexRowVector operator - (const RowVector &a, const Complex &s)
ComplexRowVector operator * (const RowVector &a, const Complex &s)
ComplexRowVector operator / (const RowVector &a, const Complex &s)

ComplexRowVector operator + (const Complex &s, const RowVector &a)
ComplexRowVector operator - (const Complex &s, const RowVector &a)
ComplexRowVector operator * (const Complex &s, const RowVector &a)
ComplexRowVector operator / (const Complex &s, const RowVector &a)

double operator * (const RowVector &a, ColumnVector &b)
Complex operator * (const RowVector &a, const ComplexColumnVector &b)
RowVector operator * (const RowVector &a, const Matrix &b)
ComplexRowVector operator * (const RowVector &a, const ComplexMatrix
    &b)

ComplexRowVector operator + (const RowVector &a, const
    ComplexRowVector &b)
ComplexRowVector operator - (const RowVector &a, const
    ComplexRowVector &b)

ComplexRowVector product (const RowVector &a, const ComplexRowVector
    &b)

```

```

ComplexRowVector quotient (const RowVector &a, const
    ComplexRowVector &b)

RowVector map (d_d_Mapper f, const RowVector &a)
void map (d_d_Mapper f)

double min (void) const
double max (void) const

ostream& operator << (ostream &os, const RowVector &a)

DiagMatrix (void)
DiagMatrix (int n)
DiagMatrix (int n, double val)
DiagMatrix (int r, int c)
DiagMatrix (int r, int c, double val)
DiagMatrix (const RowVector &a)
DiagMatrix (const ColumnVector &a)
DiagMatrix (const DiagArray<double> &a)
DiagMatrix (const DiagMatrix &a)

DiagMatrix& operator = (const DiagMatrix &a)

int operator == (const DiagMatrix &a) const
int operator != (const DiagMatrix &a) const

DiagMatrix& fill (double val)
DiagMatrix& fill (double val, int beg, int end)
DiagMatrix& fill (const ColumnVector &a)
DiagMatrix& fill (const RowVector &a)
DiagMatrix& fill (const ColumnVector &a, int beg)
DiagMatrix& fill (const RowVector &a, int beg)

DiagMatrix transpose (void) const

Matrix extract (int r1, int c1, int r2, int c2) const

RowVector row (int i) const
RowVector row (char *s) const

ColumnVector column (int i) const
ColumnVector column (char *s) const

DiagMatrix inverse (void) const
DiagMatrix inverse (int &info) const

DiagMatrix& operator += (const DiagMatrix &a)
DiagMatrix& operator -= (const DiagMatrix &a)

Matrix operator + (const DiagMatrix &a, double s)
Matrix operator - (const DiagMatrix &a, double s)

ComplexMatrix operator + (const DiagMatrix &a, const Complex &s)
ComplexMatrix operator - (const DiagMatrix &a, const Complex &s)

ComplexDiagMatrix operator * (const DiagMatrix &a, const Complex &s)

```

```

ComplexDiagMatrix operator / (const DiagMatrix &a, const Complex &s)
Matrix operator + (double s, const DiagMatrix &a)
Matrix operator - (double s, const DiagMatrix &a)
ComplexMatrix operator + (const Complex &s, const DiagMatrix &a)
ComplexMatrix operator - (const Complex &s, const DiagMatrix &a)
ComplexDiagMatrix operator * (const Complex &s, const DiagMatrix &a)
ColumnVector operator * (const DiagMatrix &a, const ColumnVector &b)
ComplexColumnVector operator * (const DiagMatrix &a, const
    ComplexColumnVector &b)
ComplexDiagMatrix operator + (const DiagMatrix &a, const
    ComplexDiagMatrix &b)
ComplexDiagMatrix operator - (const DiagMatrix &a, const
    ComplexDiagMatrix &b)
ComplexDiagMatrix product (const DiagMatrix &a, const
    ComplexDiagMatrix &b)
Matrix operator + (const DiagMatrix &a, const Matrix &b)
Matrix operator - (const DiagMatrix &a, const Matrix &b)
Matrix operator * (const DiagMatrix &a, const Matrix &b)
ComplexMatrix operator + (const DiagMatrix &a, const ComplexMatrix &b)
ComplexMatrix operator - (const DiagMatrix &a, const ComplexMatrix &b)
ComplexMatrix operator * (const DiagMatrix &a, const ComplexMatrix &b)
ColumnVector diag (void) const
ColumnVector diag (int k) const
ostream& operator << (ostream &os, const DiagMatrix &a)
ComplexMatrix (void)
ComplexMatrix (int r, int c)
ComplexMatrix (int r, int c, const Complex &val)
ComplexMatrix (const Matrix &a)
ComplexMatrix (const Array2<Complex> &a)
ComplexMatrix (const ComplexMatrix &a)
ComplexMatrix (const DiagMatrix &a)
ComplexMatrix (const DiagArray<Complex> &a)
ComplexMatrix (const ComplexDiagMatrix &a)
ComplexMatrix& operator = (const ComplexMatrix &a)
int operator == (const ComplexMatrix &a) const
int operator != (const ComplexMatrix &a) const
ComplexMatrix& insert (const Matrix &a, int r, int c)
ComplexMatrix& insert (const RowVector &a, int r, int c)
ComplexMatrix& insert (const ColumnVector &a, int r, int c)
ComplexMatrix& insert (const DiagMatrix &a, int r, int c)
ComplexMatrix& insert (const ComplexMatrix &a, int r, int c)

```

```

ComplexMatrix& insert (const ComplexRowVector &a, int r, int c)
ComplexMatrix& insert (const ComplexColumnVector &a, int r, int c)
ComplexMatrix& insert (const ComplexDiagMatrix &a, int r, int c)

ComplexMatrix& fill (double val)
ComplexMatrix& fill (const Complex &val)
ComplexMatrix& fill (double val, int r1, int c1, int r2, int c2)
ComplexMatrix& fill (const Complex &val, int r1, int c1, int r2, int c2)

ComplexMatrix append (const Matrix &a) const
ComplexMatrix append (const RowVector &a) const
ComplexMatrix append (const ColumnVector &a) const
ComplexMatrix append (const DiagMatrix &a) const

ComplexMatrix append (const ComplexMatrix &a) const
ComplexMatrix append (const ComplexRowVector &a) const
ComplexMatrix append (const ComplexColumnVector &a) const
ComplexMatrix append (const ComplexDiagMatrix &a) const

ComplexMatrix stack (const Matrix &a) const
ComplexMatrix stack (const RowVector &a) const
ComplexMatrix stack (const ColumnVector &a) const
ComplexMatrix stack (const DiagMatrix &a) const

ComplexMatrix stack (const ComplexMatrix &a) const
ComplexMatrix stack (const ComplexRowVector &a) const
ComplexMatrix stack (const ComplexColumnVector &a) const
ComplexMatrix stack (const ComplexDiagMatrix &a) const

ComplexMatrix transpose (void) const

Matrix real (const ComplexMatrix &a)
Matrix imag (const ComplexMatrix &a)
ComplexMatrix conj (const ComplexMatrix &a)

ComplexMatrix extract (int r1, int c1, int r2, int c2) const

ComplexRowVector row (int i) const
ComplexRowVector row (char *s) const

ComplexColumnVector column (int i) const
ComplexColumnVector column (char *s) const

ComplexMatrix inverse (void) const
ComplexMatrix inverse (int &info) const
ComplexMatrix inverse (int &info, double &rcond) const

ComplexMatrix fourier (void) const
ComplexMatrix ifourier (void) const

ComplexDET determinant (void) const
ComplexDET determinant (int &info) const
ComplexDET determinant (int &info, double &rcond) const

ComplexMatrix solve (const Matrix &b) const

```

```

ComplexMatrix solve (const Matrix &b, int &info) const
ComplexMatrix solve (const Matrix &b, int &info, double &rcond) const

ComplexMatrix solve (const ComplexMatrix &b) const
ComplexMatrix solve (const ComplexMatrix &b, int &info) const
ComplexMatrix solve (const ComplexMatrix &b, int &info, double &rcond)
    const

ComplexColumnVector solve (const ComplexColumnVector &b) const
ComplexColumnVector solve (const ComplexColumnVector &b, int &info)
    const

ComplexColumnVector solve (const ComplexColumnVector &b, int &info,
    double &rcond) const

ComplexMatrix lssolve (const ComplexMatrix &b) const
ComplexMatrix lssolve (const ComplexMatrix &b, int &info) const
ComplexMatrix lssolve (const ComplexMatrix &b, int &info, int &rank)
    const

ComplexColumnVector lssolve (const ComplexColumnVector &b) const
ComplexColumnVector lssolve (const ComplexColumnVector &b, int
    &info) const
ComplexColumnVector lssolve (const ComplexColumnVector &b, int &info,
    int &rank) const

ComplexMatrix& operator += (const DiagMatrix &a)
ComplexMatrix& operator -= (const DiagMatrix &a)

ComplexMatrix& operator += (const ComplexDiagMatrix &a)
ComplexMatrix& operator -= (const ComplexDiagMatrix &a)

ComplexMatrix& operator += (const Matrix &a)
ComplexMatrix& operator -= (const Matrix &a)

ComplexMatrix& operator += (const ComplexMatrix &a)
ComplexMatrix& operator -= (const ComplexMatrix &a)

Matrix operator ! (void) const

ComplexMatrix operator + (const ComplexMatrix &a, double s)
ComplexMatrix operator - (const ComplexMatrix &a, double s)
ComplexMatrix operator * (const ComplexMatrix &a, double s)
ComplexMatrix operator / (const ComplexMatrix &a, double s)

ComplexMatrix operator + (double s, const ComplexMatrix &a)
ComplexMatrix operator - (double s, const ComplexMatrix &a)
ComplexMatrix operator * (double s, const ComplexMatrix &a)
ComplexMatrix operator / (double s, const ComplexMatrix &a)

ComplexColumnVector operator * (const ComplexMatrix &a, const
    ColumnVector &b)

ComplexColumnVector operator * (const ComplexMatrix &a, const
    ComplexColumnVector &b)

ComplexMatrix operator + (const ComplexMatrix &a, const DiagMatrix &b)

```

```

ComplexMatrix operator - (const ComplexMatrix &a, const DiagMatrix &b)
ComplexMatrix operator * (const ComplexMatrix &a, const DiagMatrix &b)

ComplexMatrix operator + (const ComplexMatrix &a, const
    ComplexDiagMatrix &b)
ComplexMatrix operator - (const ComplexMatrix &a, const
    ComplexDiagMatrix &b)
ComplexMatrix operator * (const ComplexMatrix &a, const
    ComplexDiagMatrix &b)

ComplexMatrix operator + (const ComplexMatrix &a, const Matrix &b)
ComplexMatrix operator - (const ComplexMatrix &a, const Matrix &b)
ComplexMatrix operator * (const ComplexMatrix &a, const Matrix &b)
ComplexMatrix operator * (const ComplexMatrix &a, const ComplexMatrix
    &b)

ComplexMatrix product (const ComplexMatrix &a, const Matrix &b)
ComplexMatrix quotient (const ComplexMatrix &a, const Matrix &b)

ComplexMatrix map (c_c_Mapper f, const ComplexMatrix &a)
Matrix map (d_c_Mapper f, const ComplexMatrix &a)
void map (c_c_Mapper f)

Matrix all (void) const
Matrix any (void) const

ComplexMatrix cumprod (void) const
ComplexMatrix cumsum (void) const
ComplexMatrix prod (void) const
ComplexMatrix sum (void) const
ComplexMatrix sumsq (void) const

ComplexColumnVector diag (void) const
ComplexColumnVector diag (int k) const

ComplexColumnVector row_min (void) const
ComplexColumnVector row_min_loc (void) const

ComplexColumnVector row_max (void) const
ComplexColumnVector row_max_loc (void) const

ComplexRowVector column_min (void) const
ComplexRowVector column_min_loc (void) const

ComplexRowVector column_max (void) const
ComplexRowVector column_max_loc (void) const

ostream& operator << (ostream &os, const ComplexMatrix &a)
istream& operator >> (istream &is, ComplexMatrix &a)

ComplexColumnVector (void)
ComplexColumnVector (int n)
ComplexColumnVector (int n, const Complex &val)
ComplexColumnVector (const ColumnVector &a)

```

```

ComplexColumnVector (const Array<Complex> &a)
ComplexColumnVector (const ComplexColumnVector &a)

ComplexColumnVector& operator = (const ComplexColumnVector &a)

int operator == (const ComplexColumnVector &a) const
int operator != (const ComplexColumnVector &a) const

ComplexColumnVector& insert (const ColumnVector &a, int r)
ComplexColumnVector& insert (const ComplexColumnVector &a, int r)

ComplexColumnVector& fill (double val)
ComplexColumnVector& fill (const Complex &val)
ComplexColumnVector& fill (double val, int r1, int r2)
ComplexColumnVector& fill (const Complex &val, int r1, int r2)

ComplexColumnVector stack (const ColumnVector &a) const
ComplexColumnVector stack (const ComplexColumnVector &a) const

ComplexRowVector transpose (void) const

ColumnVector real (const ComplexColumnVector &a)
ColumnVector imag (const ComplexColumnVector &a)
ComplexColumnVector conj (const ComplexColumnVector &a)

ComplexColumnVector extract (int r1, int r2) const

ComplexColumnVector& operator += (const ColumnVector &a)
ComplexColumnVector& operator -= (const ColumnVector &a)

ComplexColumnVector& operator += (const ComplexColumnVector &a)
ComplexColumnVector& operator -= (const ComplexColumnVector &a)

ComplexColumnVector operator + (const ComplexColumnVector &a, double
    s)
ComplexColumnVector operator - (const ComplexColumnVector &a, double
    s)
ComplexColumnVector operator * (const ComplexColumnVector &a, double
    s)
ComplexColumnVector operator / (const ComplexColumnVector &a, double
    s)

ComplexColumnVector operator + (double s, const ComplexColumnVector
    &a)
ComplexColumnVector operator - (double s, const ComplexColumnVector
    &a)
ComplexColumnVector operator * (double s, const ComplexColumnVector
    &a)
ComplexColumnVector operator / (double s, const ComplexColumnVector
    &a)

ComplexMatrix operator * (const ComplexColumnVector &a, const
    ComplexRowVector &b)

```



```

ComplexColumnVector operator + (const ComplexColumnVector &a, const
    ColumnVector &b)
ComplexColumnVector operator - (const ComplexColumnVector &a, const
    ColumnVector &b)

ComplexColumnVector product (const ComplexColumnVector &a, const
    ColumnVector &b)
ComplexColumnVector quotient (const ComplexColumnVector &a, const
    ColumnVector &b)

ComplexColumnVector map (c_c_Mapper f, const ComplexColumnVector &a)
ColumnVector map (d_c_Mapper f, const ComplexColumnVector &a)
void map (c_c_Mapper f)

Complex min (void) const
Complex max (void) const

ostream& operator << (ostream &os, const ComplexColumnVector &a)

ComplexRowVector (void)
ComplexRowVector (int n)
ComplexRowVector (int n, const Complex &val)
ComplexRowVector (const RowVector &a)
ComplexRowVector (const Array<Complex> &a)
ComplexRowVector (const ComplexRowVector &a)

ComplexRowVector& operator = (const ComplexRowVector &a)

int operator == (const ComplexRowVector &a) const
int operator != (const ComplexRowVector &a) const

ComplexRowVector& insert (const RowVector &a, int c)
ComplexRowVector& insert (const ComplexRowVector &a, int c)

ComplexRowVector& fill (double val)
ComplexRowVector& fill (const Complex &val)
ComplexRowVector& fill (double val, int c1, int c2)
ComplexRowVector& fill (const Complex &val, int c1, int c2)

ComplexRowVector append (const RowVector &a) const
ComplexRowVector append (const ComplexRowVector &a) const

ComplexColumnVector transpose (void) const

RowVector real (const ComplexRowVector &a)
RowVector imag (const ComplexRowVector &a)
ComplexRowVector conj (const ComplexRowVector &a)

ComplexRowVector extract (int c1, int c2) const

ComplexRowVector& operator += (const RowVector &a)
ComplexRowVector& operator -= (const RowVector &a)

ComplexRowVector& operator += (const ComplexRowVector &a)
ComplexRowVector& operator -= (const ComplexRowVector &a)

ComplexRowVector operator + (const ComplexRowVector &a, double s)

```

```

ComplexRowVector operator - (const ComplexRowVector &a, double s)
ComplexRowVector operator * (const ComplexRowVector &a, double s)
ComplexRowVector operator / (const ComplexRowVector &a, double s)

ComplexRowVector operator + (double s, const ComplexRowVector &a)
ComplexRowVector operator - (double s, const ComplexRowVector &a)
ComplexRowVector operator * (double s, const ComplexRowVector &a)
ComplexRowVector operator / (double s, const ComplexRowVector &a)

Complex operator * (const ComplexRowVector &a, const ColumnVector &b)

Complex operator * (const ComplexRowVector &a, const
    ComplexColumnVector &b)

ComplexRowVector operator * (const ComplexRowVector &a, const
    ComplexMatrix &b)

ComplexRowVector operator + (const ComplexRowVector &a, const
    RowVector &b)
ComplexRowVector operator - (const ComplexRowVector &a, const
    RowVector &b)

ComplexRowVector product (const ComplexRowVector &a, const RowVector
    &b)
ComplexRowVector quotient (const ComplexRowVector &a, const
    RowVector &b)

ComplexRowVector map (c_c_Mapper f, const ComplexRowVector &a)
RowVector map (d_c_Mapper f, const ComplexRowVector &a)
void map (c_c_Mapper f)

Complex min (void) const
Complex max (void) const

ostream& operator << (ostream &os, const ComplexRowVector &a)

ComplexDiagMatrix (void)
ComplexDiagMatrix (int n)
ComplexDiagMatrix (int n, const Complex &val)
ComplexDiagMatrix (int r, int c)
ComplexDiagMatrix (int r, int c, const Complex &val)
ComplexDiagMatrix (const RowVector &a)
ComplexDiagMatrix (const ComplexRowVector &a)
ComplexDiagMatrix (const ColumnVector &a)
ComplexDiagMatrix (const ComplexColumnVector &a)
ComplexDiagMatrix (const DiagMatrix &a)
ComplexDiagMatrix (const DiagArray<Complex> &a)
ComplexDiagMatrix (const ComplexDiagMatrix &a)

ComplexDiagMatrix& operator = (const ComplexDiagMatrix &a)

int operator == (const ComplexDiagMatrix &a) const
int operator != (const ComplexDiagMatrix &a) const

ComplexDiagMatrix& fill (double val)

```

```

ComplexDiagMatrix& fill (const Complex &val)
ComplexDiagMatrix& fill (double val, int beg, int end)
ComplexDiagMatrix& fill (const Complex &val, int beg, int end)
ComplexDiagMatrix& fill (const ColumnVector &a)
ComplexDiagMatrix& fill (const ComplexColumnVector &a)
ComplexDiagMatrix& fill (const RowVector &a)
ComplexDiagMatrix& fill (const ComplexRowVector &a)
ComplexDiagMatrix& fill (const ColumnVector &a, int beg)
ComplexDiagMatrix& fill (const ComplexColumnVector &a, int beg)
ComplexDiagMatrix& fill (const RowVector &a, int beg)
ComplexDiagMatrix& fill (const ComplexRowVector &a, int beg)

ComplexDiagMatrix transpose (void) const

DiagMatrix real (const ComplexDiagMatrix &a)
DiagMatrix imag (const ComplexDiagMatrix &a)
ComplexDiagMatrix conj (const ComplexDiagMatrix &a)

ComplexMatrix extract (int r1, int c1, int r2, int c2) const

ComplexRowVector row (int i) const
ComplexRowVector row (char *s) const

ComplexColumnVector column (int i) const
ComplexColumnVector column (char *s) const

ComplexDiagMatrix inverse (int &info) const
ComplexDiagMatrix inverse (void) const

ComplexDiagMatrix& operator += (const DiagMatrix &a)
ComplexDiagMatrix& operator -= (const DiagMatrix &a)

ComplexDiagMatrix& operator += (const ComplexDiagMatrix &a)
ComplexDiagMatrix& operator -= (const ComplexDiagMatrix &a)

ComplexMatrix operator + (const ComplexDiagMatrix &a, double s)
ComplexMatrix operator - (const ComplexDiagMatrix &a, double s)

ComplexMatrix operator + (const ComplexDiagMatrix &a, const Complex
    &s)
ComplexMatrix operator - (const ComplexDiagMatrix &a, const Complex
    &s)

ComplexDiagMatrix operator * (const ComplexDiagMatrix &a, double s)
ComplexDiagMatrix operator / (const ComplexDiagMatrix &a, double s)

ComplexMatrix operator + (double s, const ComplexDiagMatrix &a)
ComplexMatrix operator - (double s, const ComplexDiagMatrix &a)

ComplexMatrix operator + (const Complex &s, const ComplexDiagMatrix
    &a)
ComplexMatrix operator - (const Complex &s, const ComplexDiagMatrix
    &a)

ComplexDiagMatrix operator * (double s, const ComplexDiagMatrix &a)

```

```

ComplexColumnVector operator * (const ComplexDiagMatrix &a, const
    ColumnVector &b)
ComplexColumnVector operator * (const ComplexDiagMatrix &a, const
    ComplexColumnVector &b)
ComplexDiagMatrix operator + (const ComplexDiagMatrix &a, const
    DiagMatrix &b)
ComplexDiagMatrix operator - (const ComplexDiagMatrix &a, const
    DiagMatrix &b)
ComplexDiagMatrix product (const ComplexDiagMatrix &a, const
    DiagMatrix &b)
ComplexMatrix operator + (const ComplexDiagMatrix &a, const Matrix &b)
ComplexMatrix operator - (const ComplexDiagMatrix &a, const Matrix &b)
ComplexMatrix operator * (const ComplexDiagMatrix &a, const Matrix &b)
ComplexMatrix operator + (const ComplexDiagMatrix &a, const
    ComplexMatrix &b)
ComplexMatrix operator - (const ComplexDiagMatrix &a, const
    ComplexMatrix &b)
ComplexMatrix operator * (const ComplexDiagMatrix &a, const
    ComplexMatrix &b)
ComplexColumnVector diag (void) const
ComplexColumnVector diag (int k) const
ostream& operator << (ostream &os, const ComplexDiagMatrix &a)

```

## 5 Matrix Factorizations

```

AEPBALANCE (void)
AEPBALANCE (const Matrix &a, const char *balance_job)
AEPBALANCE (const AEPBALANCE &a)

AEPBALANCE& operator = (const AEPBALANCE &a)

Matrix balanced_matrix (void) const
Matrix balancing_matrix (void) const

ostream& operator << (ostream &os, const AEPBALANCE &a)

ComplexAEPBALANCE (void)
ComplexAEPBALANCE (const ComplexMatrix &a, const char *balance_job)
ComplexAEPBALANCE (const ComplexAEPBALANCE &a)

ComplexAEPBALANCE& operator = (const ComplexAEPBALANCE &a)

ComplexMatrix balanced_matrix (void) const
ComplexMatrix balancing_matrix (void) const

ostream& operator << (ostream &os, const ComplexAEPBALANCE &a)

DET (void)
DET (const DET &a)

DET& operator = (const DET &a)

int value_will_overflow (void) const
int value_will_underflow (void) const

double coefficient (void) const
int exponent (void) const
double value (void) const

ostream& operator << (ostream &os, const DET &a)

ComplexDET (void)
ComplexDET (const ComplexDET &a)

ComplexDET& operator = (const ComplexDET &a)

int value_will_overflow (void) const
int value_will_underflow (void) const

Complex coefficient (void) const
int exponent (void) const
Complex value (void) const

ostream& operator << (ostream &os, const ComplexDET &a)

GEPBALANCE (void)
GEPBALANCE (const Matrix &a, const Matrix &, const char *balance_job)
GEPBALANCE (const GEPBALANCE &a)

GEPBALANCE& operator = (const GEPBALANCE &a)

```

```

Matrix balanced_a_matrix (void) const
Matrix balanced_b_matrix (void) const
Matrix left_balancing_matrix (void) const
Matrix right_balancing_matrix (void) const
ostream& operator << (ostream &os, const GEPBALANCE &a)
CHOL (void)
CHOL (const Matrix &a)
CHOL (const Matrix &a, int &info)
CHOL (const CHOL &a)
CHOL& operator = (const CHOL &a)
Matrix chol_matrix (void) const
ostream& operator << (ostream &os, const CHOL &a)
ComplexCHOL (void)
ComplexCHOL (const ComplexMatrix &a)
ComplexCHOL (const ComplexMatrix &a, int &info)
ComplexCHOL (const ComplexCHOL &a)
ComplexCHOL& operator = (const ComplexCHOL &a)
ComplexMatrix chol_matrix (void) const
ostream& operator << (ostream &os, const ComplexCHOL &a)
HESS (void)
HESS (const Matrix &a)
HESS (const Matrix&a, int &info)
HESS (const HESS &a)
HESS& operator = (const HESS &a)
Matrix hess_matrix (void) const
Matrix unitary_hess_matrix (void) const
ostream& operator << (ostream &os, const HESS &a)
ComplexHESS (void)
ComplexHESS (const ComplexMatrix &a)
ComplexHESS (const ComplexMatrix &a, int &info)
ComplexHESS (const ComplexHESS &a)
ComplexHESS& operator = (const ComplexHESS &a)
ComplexMatrix hess_matrix (void) const
ComplexMatrix unitary_hess_matrix (void) const
ostream& operator << (ostream &os, const ComplexHESS &a)
SCHUR (void)
SCHUR (const Matrix &a, const char *ord)
SCHUR (const Matrix &a, const char *ord, int &info)
SCHUR (const SCHUR &a, const char *ord)
SCHUR& operator = (const SCHUR &a)

```

```

Matrix schur_matrix (void) const
Matrix unitary_matrix (void) const

ostream& operator << (ostream &os, const SCHUR &a)

ComplexSCHUR (void)
ComplexSCHUR (const ComplexMatrix &a, const char *ord)
ComplexSCHUR (const ComplexMatrix &a, const char *ord, int &info)
ComplexSCHUR (const ComplexSCHUR &a, const char *ord)

ComplexSCHUR& operator = (const ComplexSCHUR &a)

ComplexMatrix schur_matrix (void) const
ComplexMatrix unitary_matrix (void) const

ostream& operator << (ostream &os, const ComplexSCHUR &a)

SVD (void)
SVD (const Matrix &a)
SVD (const Matrix &a, int &info)
SVD (const SVD &a)

SVD& operator = (const SVD &a)

DiagMatrix singular_values (void) const
Matrix left_singular_matrix (void) const
Matrix right_singular_matrix (void) const

ostream& operator << (ostream &os, const SVD &a)

ComplexSVD (void)
ComplexSVD (const ComplexMatrix &a)
ComplexSVD (const ComplexMatrix &a, int &info)
ComplexSVD (const ComplexSVD &a)

ComplexSVD& operator = (const ComplexSVD &a)

DiagMatrix singular_values (void) const
ComplexMatrix left_singular_matrix (void) const
ComplexMatrix right_singular_matrix (void) const

ostream& operator << (ostream &os, const ComplexSVD &a)

EIG (void)
EIG (const Matrix &a)
EIG (const Matrix &a, int &info)
EIG (const ComplexMatrix &a)
EIG (const ComplexMatrix &a, int &info)
EIG (const EIG &a)

EIG& operator = (const EIG &a)

ComplexColumnVector eigenvalues (void) const
ComplexMatrix eigenvectors (void) const

ostream& operator << (ostream &os, const EIG &a)

```

```

LU (void)
LU (const Matrix &a)
LU (const LU &a)

LU& operator = (const LU &a)

Matrix L (void) const
Matrix U (void) const
Matrix P (void) const

ostream& operator << (ostream &os, const LU &a)

ComplexLU (void)
ComplexLU (const ComplexMatrix &a)
ComplexLU (const ComplexLU &a)

ComplexLU& operator = (const ComplexLU &a)

ComplexMatrix L (void) const
ComplexMatrix U (void) const
Matrix P (void) const

ostream& operator << (ostream &os, const ComplexLU &a)

QR (void)
QR (const Matrix &A)
QR (const QR &a)

QR& operator = (const QR &a)

Matrix Q (void) const
Matrix R (void) const

ostream& operator << (ostream &os, const QR &a)

ComplexQR (void)
ComplexQR (const ComplexMatrix &A)
ComplexQR (const ComplexQR &a)

ComplexQR& operator = (const ComplexQR &a)

ComplexMatrix Q (void) const
ComplexMatrix R (void) const

ostream& operator << (ostream &os, const ComplexQR &a)

```



## 6 Ranges

```
Range (void)
Range (const Range &r)
Range (double b, double l)
Range (double b, double l, double i)

double base (void) const
double limit (void) const
double inc (void) const

void set_base (double b)
void set_limit (double l)
void set_inc (double i)

int nelem (void) const

double min (void) const
double max (void) const

void sort (void)

ostream& operator << (ostream &os, const Range &r)
istream& operator >> (istream &is, Range &r)

void print_range (void)
```

## 7 Nonlinear Functions

```
NLFunc (void)
NLFunc (const nonlinear_fcn)
NLFunc (const nonlinear_fcn, const jacobian_fcn)
NLFunc (const NLFunc &a)

NLFunc& operator = (const NLFunc &a)

nonlinear_fcn function (void) const;

NLFunc& set_function (const nonlinear_fcn f)
jacobian_fcn jacobian_function (void) const;

NLFunc& set_jacobian_function (const jacobian_fcn j)
```

## 8 Nonlinear Equations

```

NLEqn_options (void)
NLEqn_options (const NLEqn_options &opt)
NLEqn_options& operator = (const NLEqn_options &opt)
void init (void)
void copy (const NLEqn_options &opt)
void set_default_options (void)
void set_tolerance (double val)
double tolerance (void)

NLEqn (void)
NLEqn (const ColumnVector&, const NLFunc)
NLEqn (const NLEqn &a)
NLEqn& operator = (const NLEqn &a)
void resize (int n)
void set_states (const ColumnVector &x)
ColumnVector states (void) const
int size (void) const
ColumnVector solve (void)
ColumnVector solve (const ColumnVector &x)
ColumnVector solve (int &info)
ColumnVector solve (const ColumnVector &x, int &info)

```

## 9 Optimization

### 9.1 Objective Functions

```

Objective (void)
Objective (const objective_fcn)
Objective (const objective_fcn, const gradient_fcn)
Objective (const Objective &a)

Objective& operator = (const Objective &a)

objective_fcn objective_function (void) const;

Objective& set_objective_function (const objective_fcn)

gradient_fcn gradient_function (void) const;

Objective& set_gradient_function (const gradient_fcn)

```

### 9.2 Bounds

```

Bounds (void)
Bounds (int n)
Bounds (const ColumnVector lb, const ColumnVector ub)
Bounds (const Bounds &a)

Bounds& operator = (const Bounds &a)

Bounds& resize (int n)

double lower_bound (int index) const;
double upper_bound (int index) const;

ColumnVector lower_bounds (void) const;
ColumnVector upper_bounds (void) const;

int size (void) const;

Bounds& set_bound (int index, double low, double high)

Bounds& set_bounds (double low, double high)
Bounds& set_bounds (const ColumnVector lb, const ColumnVector ub)

Bounds& set_lower_bound (int index, double low)
Bounds& set_upper_bound (int index, double high)

Bounds& set_lower_bounds (double low)
Bounds& set_upper_bounds (double high)

Bounds& set_lower_bounds (const ColumnVector lb)
Bounds& set_upper_bounds (const ColumnVector ub)

ostream& operator << (ostream &os, const Bounds &b)

```

### 9.3 Linear Constraints

```

LinConst (void)
LinConst (int nclin, int nx)
LinConst (int nclin_eq, int nclin_ineq, int nx)
LinConst (const ColumnVector &lb, const Matrix &A, const ColumnVector
          &ub)
LinConst (const Matrix &A_eq, const ColumnVector &b_eq, const Matrix
          &A_ineq, const ColumnVector &b_ineq)
LinConst (const LinConst &a)
LinConst& operator = (const LinConst &a)
LinConst& resize (int nclin, int n)
Matrix constraint_matrix (void) const;
LinConst& set_constraint_matrix (const Matrix &A)
Matrix eq_constraint_matrix (void) const;
Matrix ineq_constraint_matrix (void) const;
ColumnVector eq_constraint_vector (void) const;
ColumnVector ineq_constraint_vector (void) const;
ostream& operator << (ostream &os, const LinConst &b)

```

### 9.4 Nonlinear Constraints

```

NLConst (void)
NLConst (int n)
NLConst (const ColumnVector lb, const NLFunc f, const ColumnVector ub)
NLConst (const NLConst &a)
NLConst& operator = (const NLConst &a)

```

### 9.5 Quadratic Programming

```

QP (void)
QP (const ColumnVector &x, const Matrix &H)
QP (const ColumnVector &x, const Matrix &H, const ColumnVector &c)
QP (const ColumnVector &x, const Matrix &H, const Bounds &b)
QP (const ColumnVector &x, const Matrix &H, const LinConst &lc)
QP (const ColumnVector &x, const Matrix &H, const ColumnVector &c, const
    Bounds &b)
QP (const ColumnVector &x, const Matrix &H, const ColumnVector &c, const
    LinConst &lc)
QP (const ColumnVector &x, const Matrix &H, const Bounds &b, const
    LinConst &lc)
QP (const ColumnVector &x, const Matrix &H, const ColumnVector &c, const
    Bounds &b, const LinConst &lc)
virtual ColumnVector minimize (void)

```

```

virtual ColumnVector minimize (double &objf)
virtual ColumnVector minimize (double &objf, int &inform)
virtual ColumnVector minimize (double &objf, int &inform,
    ColumnVector &lambda) = 0;

virtual ColumnVector minimize (const ColumnVector &x)
virtual ColumnVector minimize (const ColumnVector &x, double &objf)
virtual ColumnVector minimize (const ColumnVector &x, double &objf,
    int &inform)
virtual ColumnVector minimize (const ColumnVector &x, double &objf,
    int &inform, ColumnVector &lambda)

ColumnVector minimize (double &objf, int &inform, ColumnVector
    &lambda)

```

## 9.6 Nonlinear Programming

```

NLP (void)
NLP (const ColumnVector &x, const Objective &phi)
NLP (const ColumnVector &x, const Objective &phi, const Bounds &b)
NLP (const ColumnVector &x, const Objective &phi, const Bounds &b, const
    LinConst &lc)
NLP (const ColumnVector &x, const Objective &phi, const Bounds &b, const
    LinConst &lc, const NLConst &nlc)
NLP (const ColumnVector &x, const Objective &phi, const LinConst &lc)
NLP (const ColumnVector &x, const Objective &phi, const LinConst &lc,
    const NLConst &nlc)
NLP (const ColumnVector &x, const Objective &phi, const NLConst &nlc)
NLP (const ColumnVector &x, const Objective &phi, const Bounds &b, const
    NLConst &nlc)

NLP& operator = (const NLP &a)

int size (void) const

ColumnVector minimize (void)
ColumnVector minimize (double &objf)
ColumnVector minimize (double &objf, int &inform)
ColumnVector minimize (double &objf, int &inform, ColumnVector
    &lambda)

ColumnVector minimize (const ColumnVector &x)
ColumnVector minimize (const ColumnVector &x, double &objf)
ColumnVector minimize (const ColumnVector &x, double &objf, int
    &inform)
ColumnVector minimize (const ColumnVector &x, double &objf, int
    &inform, ColumnVector &lambda)

```

## 10 Quadrature

```

Quad (integrand_fcn fcn)
Quad (integrand_fcn fcn, double abs, double rel)

virtual double integrate (void)
virtual double integrate (int &ier)
virtual double integrate (int &ier, int &neval)
virtual double integrate (int &ier, int &neval, double &abserr) = 0

Quad_options (void)
Quad_options (const Quad_options &opt)
Quad_options& operator = (const Quad_options &opt)

void init (void)
void copy (const Quad_options &opt)
void set_default_options (void)
void set_absolute_tolerance (double val)
void set_relative_tolerance (double val)

double absolute_tolerance (void)
double relative_tolerance (void)

DefQuad (integrand_fcn fcn)
DefQuad (integrand_fcn fcn, double ll, double ul)
DefQuad (integrand_fcn fcn, double ll, double ul, double abs, double rel)
DefQuad (integrand_fcn fcn, double ll, double ul, const ColumnVector
        &sing)
DefQuad (integrand_fcn fcn, const ColumnVector &sing, double abs, double
        rel)
DefQuad (integrand_fcn fcn, const ColumnVector &sing)
DefQuad (integrand_fcn fcn, double ll, double ul, const ColumnVector
        &sing, double abs, double rel)

IndefQuad (integrand_fcn fcn)
IndefQuad (integrand_fcn fcn, double b, IntegralType t)
IndefQuad (integrand_fcn fcn, double b, IntegralType t, double abs, double
        rel)
IndefQuad (integrand_fcn fcn, double abs, double rel)

```

### 10.1 Collocation Weights

```

CollocWt (void)
CollocWt (int n, int inc_l, int inc_r)
CollocWt (int n, int inc_l, int inc_r, double l, double r)
CollocWt (int n, double a, double b, int inc_l, int inc_r)
CollocWt (int n, int inc_l, int inc_r, double l, double r)
CollocWt (const CollocWt&)
CollocWt& operator = (const CollocWt&)

```

```

CollocWt& resize (int ncol)
CollocWt& add_left (void)
CollocWt& add_right (void)
CollocWt& delete_left (void)
CollocWt& delete_right (void)
CollocWt& set_left (double val)
CollocWt& set_right (double val)
CollocWt& set_alpha (double val)
CollocWt& set_beta (double val)
int ncol (void) const
int left_included (void) const
int right_included (void) const
double left (void) const
double right (void) const
double width (void) const
double alpha (void) const
double beta (void) const
ColumnVector roots (void)
ColumnVector quad (void)
ColumnVector quad_weights (void)
Matrix first (void)
Matrix second (void)
ostream& operator << (ostream &os, const CollocWt &c)

```



## 11 Ordinary Differential Equations

```

ODE_options (void)
ODE_options (const ODE_options &opt)
ODE_options& operator = (const ODE_options &opt)
void init (void)
void copy (const ODE_options &opt)
void set_default_options (void)
void set_absolute_tolerance (double val)
void set_initial_step_size (double val)
void set_maximum_step_size (double val)
void set_minimum_step_size (double val)
void set_relative_tolerance (double val)

double absolute_tolerance (void)
double initial_step_size (void)
double maximum_step_size (void)
double minimum_step_size (void)
double relative_tolerance (void)

ODE (void)
ODE (int n)
ODE (const ColumnVector &state, double time, const ODEFunc &f)

virtual int size (void) const
virtual ColumnVector state (void) const
virtual double time (void) const
virtual void force_restart (void)
virtual void initialize (const ColumnVector &x, double t)
virtual void set_stop_time (double t)
virtual void clear_stop_time (void)
virtual ColumnVector integrate (double t)
void integrate (int nsteps, double tstep, ostream &s)

Matrix integrate (const ColumnVector &tout)
Matrix integrate (const ColumnVector &tout, const ColumnVector
                  &tcrit)

```

## 12 Differential Algebraic Equations

```

DAE (void)
DAE (int n)
DAE (const ColumnVector &x, double time, DAEFunc &f)
DAE (const ColumnVector &x, ColumnVector &xdot, double time, DAEFunc
    &f)

ColumnVector deriv (void)

virtual void initialize (const ColumnVector &x, double t)
virtual void initialize (const ColumnVector &x, ColumnVector &xdot,
    double t)

ColumnVector integrate (double t)

Matrix integrate (const ColumnVector &tout, Matrix &xdot_out)
Matrix integrate (const ColumnVector &tout, Matrix &xdot_out, const
    ColumnVector &tcrit)

```

## 13 Error Handling

## 14 Installation

## 15 Bugs

# Concept Index

## A

acknowledgements ..... 1  
arrays ..... 14

## B

bounds ..... 40  
bugs, known ..... 49

## C

collocation weights ..... 43  
contributors ..... 1  
copyright ..... 1

## D

DAE ..... 46

## F

factorizations ..... 33

## I

installation ..... 48  
installation trouble ..... 49  
integration ..... 43  
introduction ..... 13

## K

known causes of trouble ..... 49

## L

linear Constraints ..... 41

## M

matrix factorizations ..... 33  
matrix manipulations ..... 18

## N

NLP ..... 42  
nonlinear Constraints ..... 41  
nonlinear equations ..... 39  
nonlinear functions ..... 38  
nonlinear programming ..... 42  
numerical integration ..... 43

## O

objective functions ..... 40  
ODE ..... 45  
optimization ..... 40  
orthogonal collocation ..... 43

## Q

QP ..... 41  
quadratic programming ..... 41  
quadrature ..... 43

## R

ranges ..... 37

## T

troubleshooting ..... 49

## V

vector manipulations ..... 18

## W

warranty ..... 1

# Function Index

## A

absolute_tolerance	43, 45
add_left	44
add_right	44
AEPBALANCE	33
all	20, 27
alpha	44
any	20, 27
append	18, 22, 25, 29
Array<T>	14
Array2<T>	15
Array3<T>	15

## B

balanced_a_matrix	34
balanced_b_matrix	34
balanced_matrix	33
balancing_matrix	33
base	37
beta	44
Bounds	40

## C

capacity on Array<T>	14
checkelem on Array<T>	14
checkelem on Array2<T>	15
checkelem on Array3<T>	15
checkelem on DiagArray<T>	16
chol_matrix	34
CHOL	34
clear_stop_time	45
coefficient	33
CollocWt	43
cols on Array2<T>	15
cols on DiagArray<T>	16
column	18, 23, 25, 31
column_max	20, 27
column_max_loc	20, 27
column_min	20, 27
column_min_loc	20, 27
columns on Array2<T>	15
columns on DiagArray<T>	16
ColumnVector	20, 21
ComplexAEPBALANCE	33
ComplexCHOL	34
ComplexColumnVector	27, 28
ComplexDET	33
ComplexDiagMatrix	30
ComplexHESS	34
ComplexLU	36
ComplexMatrix	24
ComplexQR	36

ComplexRowVector	29
ComplexSCHUR	35
ComplexSVD	35
conj	25, 28, 29, 31
constraint_matrix	41
copy	39, 43, 45
cumprod	20, 27
cumsum	20, 27

## D

DAE	46
data on Array<T>	15
DefQuad	43
delete_left	44
delete_right	44
deriv	46
determinant	18, 25
DET	33
diag	20, 24, 27, 32
DiagArray<T>	15
DiagMatrix	23
dim1 on Array2<T>	15
dim1 on Array3<T>	15
dim1 on DiagArray<T>	16
dim2 on Array2<T>	15
dim2 on Array3<T>	15
dim2 on DiagArray<T>	16
dim3 on Array3<T>	15

## E

eigenvalues	35
eigenvectors	35
EIG	35
elem on Array<T>	14
elem on Array2<T>	15
elem on Array3<T>	15
elem on DiagArray<T>	16
eq_constraint_matrix	41
eq_constraint_vector	41
exponent	33
extract	18, 21, 22, 23, 25, 28, 29, 31

## F

fill	18, 21, 22, 23, 25, 28, 29, 30, 31
first	44
force_restart	45
fourier	18, 25
function	38

# G

```
GEPBALANCE..... 33
gradient_function..... 40
```

## H

<code>hess_matrix</code> .....	34
<code>HESS</code> .....	34

# I

ifourier	18, 25
imag	25, 28, 29, 31
inc	37
IndefQuad	43
ineq_constraint_matrix	41
ineq_constraint_vector	41
init	39, 43, 45
initial_step_size	45
initialize	45, 46
insert	18, 21, 22, 24, 25, 28, 29
integrate	43, 45, 46
inverse	18, 23, 25, 31

# J

jacobian\_function..... 38

## L

left.....	44
left_balancing_matrix.....	34
left_included.....	44
left_singular_matrix.....	35
length on Array<T>.....	14
limit.....	37
lower_bound.....	40
lower_bounds.....	40
lssolve.....	19, 26
L.....	36
LinConst.....	41
LU.....	36

## M

map.....	20, 21, 23, 27, 29, 30
Matrix.....	18
max.....	22, 23, 29, 30, 37
maximum_step_size.....	45
min.....	22, 23, 29, 30, 37
minimize.....	41, 42
minimum_step_size.....	45

N

ncol.....	44
nelem.....	37
NLConst .....	41
NLEqn .....	39
NLEqn_options .....	39
NLFunc.....	38
NLP.....	42

## O

Objective .....	40
objective_function .....	40
ODE .....	45
ODE_options .....	45
operator ! .....	19, 26
operator != .....	18, 21, 22, 23, 24, 28, 29, 30
operator () on Array<T> .....	14
operator () on Array2<T> .....	15
operator () on Array3<T> .....	15
operator () on DiagArray<T> .....	16
operator * ...	16, 17, 19, 20, 21, 22, 23, 24, 26, 27, 28, 30, 31, 32
operator + ...	16, 17, 19, 20, 21, 22, 23, 24, 26, 27, 28, 29, 30, 31, 32
operator += .....	19, 21, 22, 23, 26, 28, 29, 31
operator - ...	16, 17, 19, 20, 21, 22, 23, 24, 26, 27, 28, 29, 30, 31, 32
operator -= .....	19, 21, 22, 23, 26, 28, 29, 31
operator / ...	16, 17, 19, 21, 22, 23, 26, 28, 30, 31
operator << ..	20, 22, 23, 24, 27, 29, 30, 32, 33, 34, 35, 36, 37, 40, 41, 44
operator = ...	18, 21, 22, 23, 24, 28, 29, 30, 33, 34, 35, 36, 38, 39, 40, 41, 42, 43, 45
operator = on Array<T> .....	14
operator = on Array2<T> .....	15
operator = on Array3<T> .....	15
operator = on DiagArray<T>& .....	15
operator == .....	18, 21, 22, 23, 24, 28, 29, 30
operator >> .....	20, 27, 37

P

print_range.....	37
prod.....	20, 27
product.....	16, 17, 20, 21, 22, 24, 27, 29, 30, 32
P.....	36

## Q

Q .....	36
QP .....	41
QR .....	36
Quad .....	43
quad .....	44
Quad_options .....	43
quad_weights .....	44
quotient .....	16, 17, 20, 21, 22, 27, 29, 30



**R**

R .....	36
Range .....	37
real .....	25, 28, 29, 31
relative_tolerance .....	43, 45
resize .....	39, 40, 41, 44
resize on Array<T> .....	14
resize on Array2<T> .....	15
resize on Array3<T> .....	15
resize on DiagArray<T> .....	16
right .....	44
right_balancing_matrix .....	34
right_included .....	44
right_singular_matrix .....	35
roots .....	44
row .....	18, 23, 25, 31
row_max .....	20, 27
row_max_loc .....	20, 27
row_min .....	20, 27
row_min_loc .....	20, 27
rows on Array2<T> .....	15
rows on DiagArray<T> .....	16
RowVector .....	22

**S**

schur_matrix .....	35
SCHUR .....	34
second .....	44
set_absolute_tolerance .....	43, 45
set_alpha .....	44
set_base .....	37
set_beta .....	44
set_bound .....	40
set_bounds .....	40
set_constraint_matrix .....	41
set_default_options .....	39, 43, 45
set_function .....	38
set_gradient_function .....	40
set_inc .....	37
set_initial_step_size .....	45
set_jacobian_function .....	38
set_left .....	44
set_limit .....	37
set_lower_bound .....	40
set_lower_bounds .....	40
set_maximum_step_size .....	45

set_minimum_step_size .....	45
set_objective_function .....	40
set_relative_tolerance .....	43, 45
set_right .....	44
set_states .....	39
set_stop_time .....	45
set_tolerance .....	39
set_upper_bound .....	40
set_upper_bounds .....	40
singular_values .....	35
size .....	39, 40, 42, 45
solve .....	18, 19, 25, 26, 39
sort .....	37
stack .....	18, 21, 25, 28
state .....	45
states .....	39
sum .....	20, 27
sumsq .....	20, 27
SVD .....	35

**T**

time .....	45
tolerance .....	39
transpose .....	18, 21, 22, 23, 25, 28, 29, 31

**U**

unitary_hess_matrix .....	34
unitary_matrix .....	35
upper_bound .....	40
upper_bounds .....	40
U .....	36

**V**

value .....	33
value_will_overflow .....	33
value_will_underflow .....	33

**W**

width .....	44
-------------	----

**X**

xelem on Array<T> .....	14
-------------------------	----