



# **GiST news and prospects**

Andrey Borodin



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Open source software is  
made and maintained  
by people, for people

Slides ->



Open source software is  
made and maintained  
by people, for people

in the beginning was  
the word...  
scientific paper



# Generalized Search Trees for Database Systems

(Extended Abstract)

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## Abstract

This paper introduces the Generalized Search Tree (GiST), an index structure supporting an extensible set of queries and data types. The GiST allows new data types to be indexed in a manner supporting queries natural to the types; this is in contrast to previous work on tree extensibility which only supported the traditional set of equality and range predicates. In a single data structure, the GiST provides all the basic search tree logic required by a database system, thereby unifying disparate structures such as B+-trees and R-trees in a single piece of code, and opening the application of search trees to general extensibility.

To illustrate the flexibility of the GiST, we provide simple method implementations that allow it to behave like a B+-tree, an R-tree, and an *RD-tree*, a new index for data with set-valued attributes. We also present a preliminary performance analysis of RD-trees, which leads to discussion on the nature of tree indices and how they behave for various datasets.

## 1 Introduction

An efficient implementation of search trees is crucial for any database system. In traditional relational systems, B+-trees [Com79] were sufficient for the sorts of queries posed on the usual set of alphanumeric data types. Today, database systems are increasingly being deployed to support new applications such as geographic information systems, multimedia systems, CAD tools, document libraries, sequence databases, financial classification, and biological databases.

developing domain-specific search trees is problematic. The effort required to implement and maintain such data structures is high. As new applications need to be supported, new tree structures have to be developed from scratch, requiring new implementations of the usual tree facilities for search, maintenance, concurrency control and recovery.

2. *Search Trees For Extensible Data Types:* As an alternative to developing new data structures, existing data structures such as B+-trees and R-trees can be made *extensible* in the data types they support [Sto86]. For example, B+-trees can be used to index any data with a linear ordering, supporting equality or linear range queries over that data. While this provides extensibility in the data that can be indexed, it does not extend the set of queries which can be supported by the tree. Regardless of the type of data stored in a B+-tree, the only queries that can benefit from the tree are those containing equality and linear range predicates. Similarly in an R-tree, the only queries that can use the tree are those containing equality, overlap and containment predicates. This inflexibility presents significant problems for new applications, since traditional queries on linear orderings and spatial location are unlikely to be apropos for new data types.

In this paper we present a third direction for extending search tree technology. We introduce a new data structure



# **Access Methods for Next-Generation Database Systems**

by

**Marcel Kornacker**

Diplom Informatik (Universität Hamburg) 1995  
M.S. (University of California, Berkeley) 1997

A dissertation submitted in partial satisfaction of the  
requirements for the degree of  
**Doctor of Philosophy**

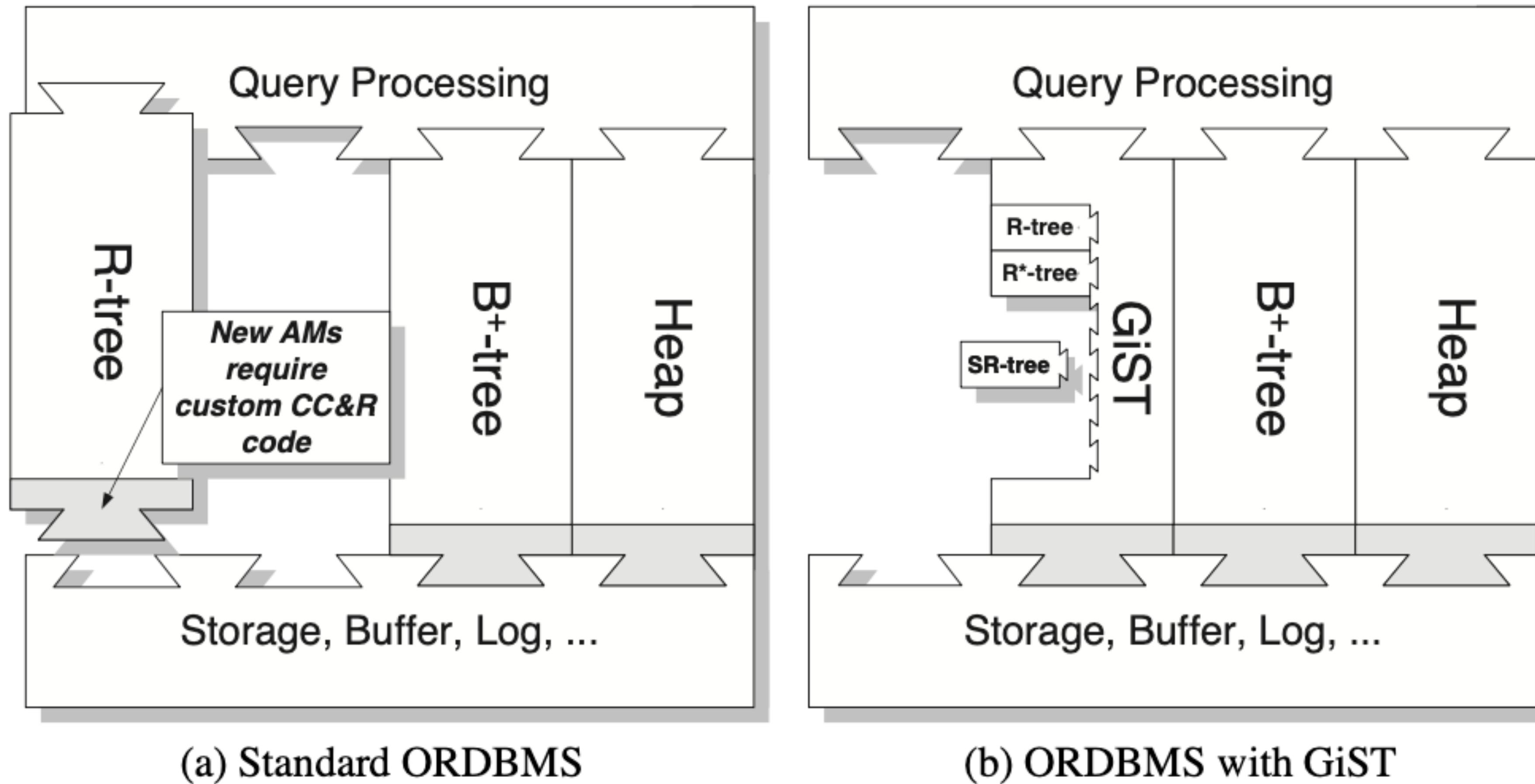


Figure 2.1: Access method interfaces – the database extender's perspective.

# GiST for PostgreSQL



Oleg      Teodor

PostgreSQL: Documentation: 16 X +

https://www.postgresql.org/docs/16/gist-intro.html

25th May 2023: PostgreSQL 16 Beta 1 Released!

Documentation → PostgreSQL 16  
Supported Versions: Current (15) / 14 / 13 / 12 / 11  
Development Versions: 16 / devel  
Unsupported versions: 10 / 9.6 / 9.5 / 9.4 / 9.3 / 9.2 /  
9.1 / 9.0 / 8.4 / 8.3 / 8.2

This documentation is for an unsupported version of PostgreSQL.  
You may want to view the same page for the current version, or one of the other supported versions listed above instead.

68.1. Introduction  
Prev Up Chapter 68. GiST Indexes Home Next

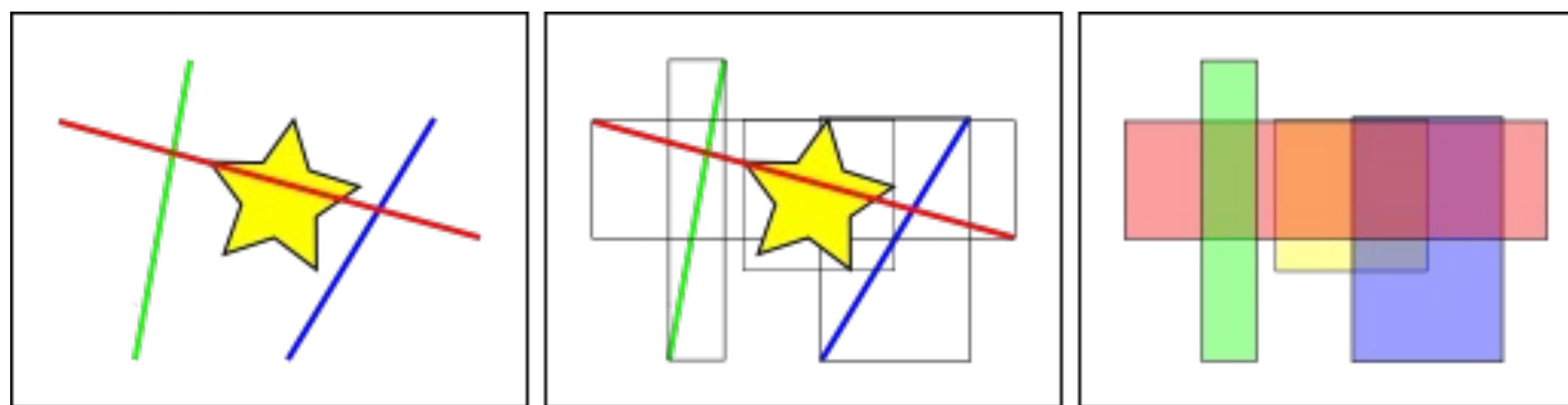
## 68.1. Introduction

GiST stands for Generalized Search Tree. It is a balanced, tree-structured access method, that acts as a base template in which to implement arbitrary indexing schemes. B-trees, R-trees and many other indexing schemes can be implemented in GiST.

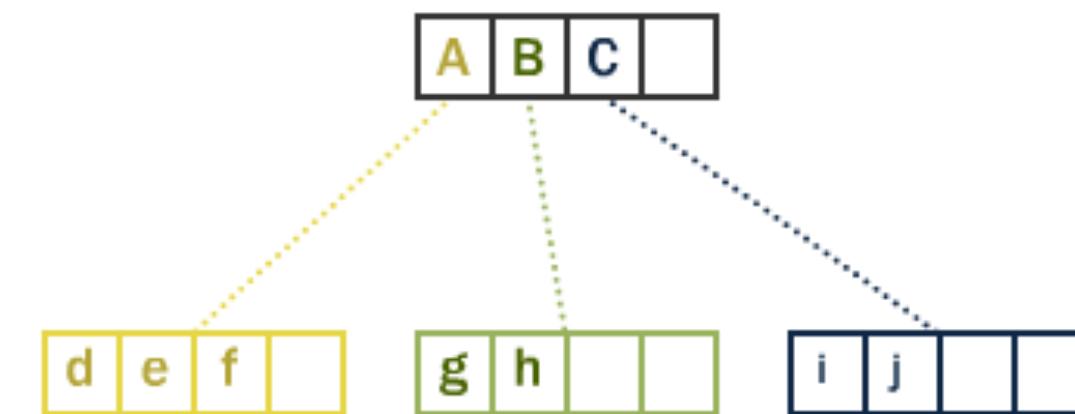
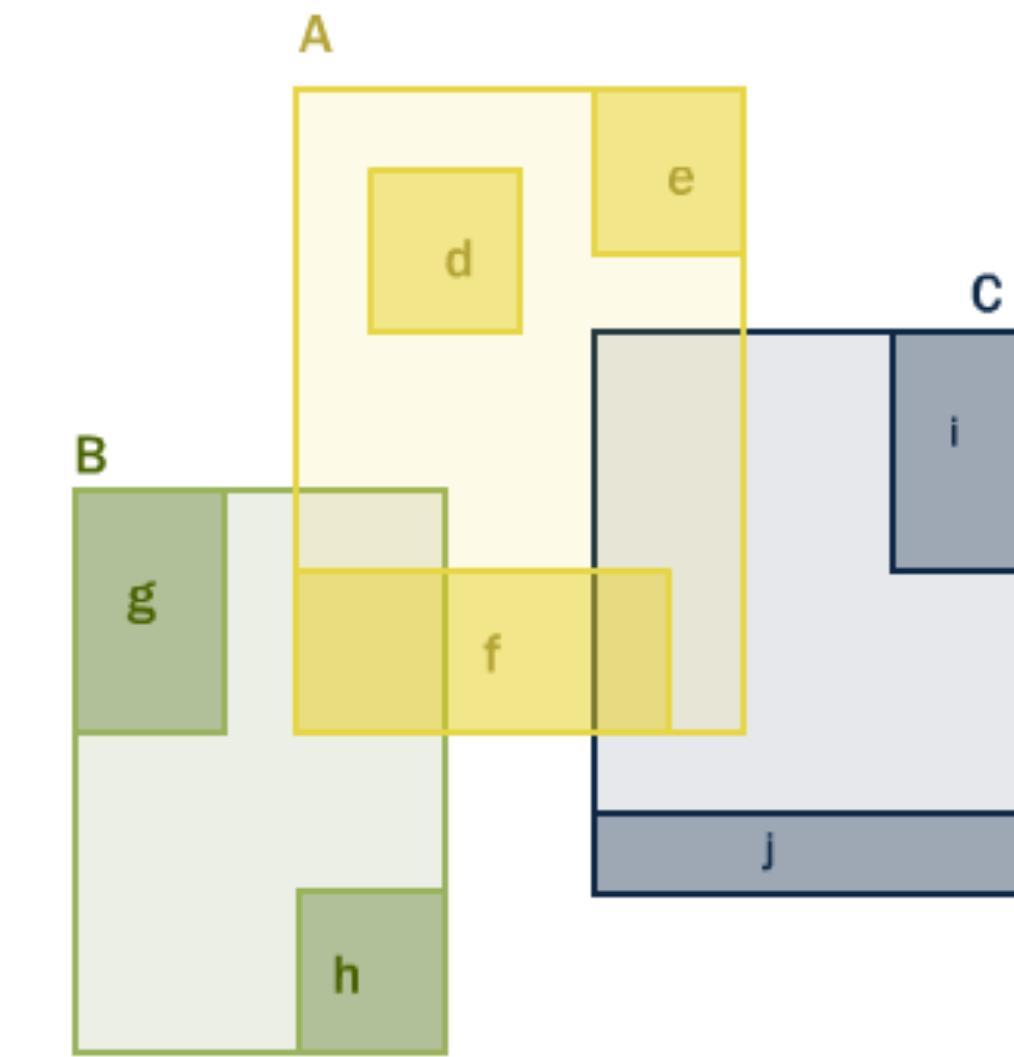
One advantage of GiST is that it allows the development of custom data types with the appropriate access methods, by an expert in the domain of the data type, rather than a database expert.

Some of the information here is derived from the University of California at Berkeley's GiST Indexing Project [web site](#) and Marcel Kornacker's thesis, [Access Methods for Next-Generation Database Systems](#). The GiST implementation in PostgreSQL is primarily maintained by Teodor Sigaev and Oleg Bartunov, and there is more information on their [web site](#).

# PostGIS



R-tree Hierarchy



# Fast forward to our days

# Postgres 11: predicate locking

## Predicate locking in Gist index

	<a href="#">Edit</a> <a href="#">Comment/Review ▾</a> <a href="#">Change Status ▾</a>
<b>Title</b>	Predicate locking in Gist index
<b>Topic</b>	Server Features
<b>Created</b>	2017-06-16 17:01:13
<b>Last modified</b>	2018-03-27 12:44:58 (5 years, 2 months ago)
<b>Latest email</b>	2018-03-27 12:44:48 (5 years, 2 months ago)
<b>Status</b>	<span style="background-color: #2e7131; color: white; padding: 2px 5px;">Committed</span> <span style="background-color: #f0adbe; border-radius: 4px; color: black; padding: 2px 5px;">Moved to next CF</span> <span style="background-color: #f0adbe; border-radius: 4px; color: black; padding: 2px 5px;">Moved to next CF</span> <span style="background-color: #f0adbe; border-radius: 4px; color: black; padding: 2px 5px;">Moved to next CF</span>
<b>Target version</b>	
<b>Authors</b>	Shubham Barai (shubham)
<b>Reviewers</b>	Fedor Sigaev (sigaev), Alexander Korotkov (smagen), Andrey Borodin (x4m)
<b>Committer</b>	Fedor Sigaev (sigaev)



# Postgres 12: covering GiST

```
CREATE INDEX on tbl USING gist(c4) INCLUDE (c3);
```

# Covering GiST indexes

	<a href="#">Edit</a> <a href="#">Comment/Review ▾</a> <a href="#">Change Status ▾</a>
<b>Title</b>	Covering GiST indexes
<b>Topic</b>	Server Features
<b>Created</b>	2018-04-13 13:38:52
<b>Last modified</b>	2019-03-15 10:52:09 (4 years, 2 months ago)
<b>Latest email</b>	2019-03-10 16:42:12 (4 years, 2 months ago)
<b>Status</b>	<a href="#">2019-03: Committed</a> <a href="#">2019-01: Moved to next CF</a> <a href="#">2018-11: Moved to next CF</a> <a href="#">2018-09: Moved to next CF</a> <a href="#">2018-07: Moved to next CF</a>
<b>Target version</b>	<a href="#">12</a>
<b>Authors</b>	Andrey Borodin (x4m)
<b>Reviewers</b>	Andreas Karlsson (kandreas)
<b>Committer</b>	Alexander Korotkov (smagen)



Tom was involved in every single feature in this talk



### **Fix GiST buffering build to work when there are included columns.**

gistRelocateBuildBuffersOnSplit did not get the memo about which attribute count to use. This could lead to a crash if there were included columns and buffering build was chosen. (Because there are random page-split decisions elsewhere in GiST index build, the crashes are not entirely deterministic.)

Back-patch to v12 where GiST gained support for included columns.

Pavel Borisov

Discussion: <https://postgr.es/m/CALT9ZEECCV5m7wxg46PC-7x-EybUmnpuBGi>

⌚ master  
⌚ REL\_16\_BETA1 ... REL\_14\_BETA1

 tglsfdc committed on Oct 13, 2020



### **✓ Fix dereference of dangling pointer in GiST index buffering build.**

gistBuildCallback tried to fetch the size of an index tuple that might have already been freed by gistProcessEmptyingQueue. While this seems to usually be harmless in production builds, in principle it could result in a SIGSEGV, or more likely a bogus value for indtuplesSize leading to poor page-split decisions later in the build.

Patch by Alexander Lakhin (commentary by Pavel Borisov and me). Back-patch to all supported branches.

Discussion: <https://postgr.es/m/16329-7a6aa9b6fa1118a1@postgresql.org>  
Discussion: <https://postgr.es/m/17874-63ca6c7ce42d2103@postgresql.org>

⌚ master  
⌚ REL\_16\_BETA1

 tglsfdc committed on Mar 29

# Feature can be further improved

```
CREATE INDEX on tbl USING gist(column1) INCLUDE (column1);
```

-- if column1 has no IndexOnlyScan-supporting opclass, planner will  
not use IndexOnlyScan

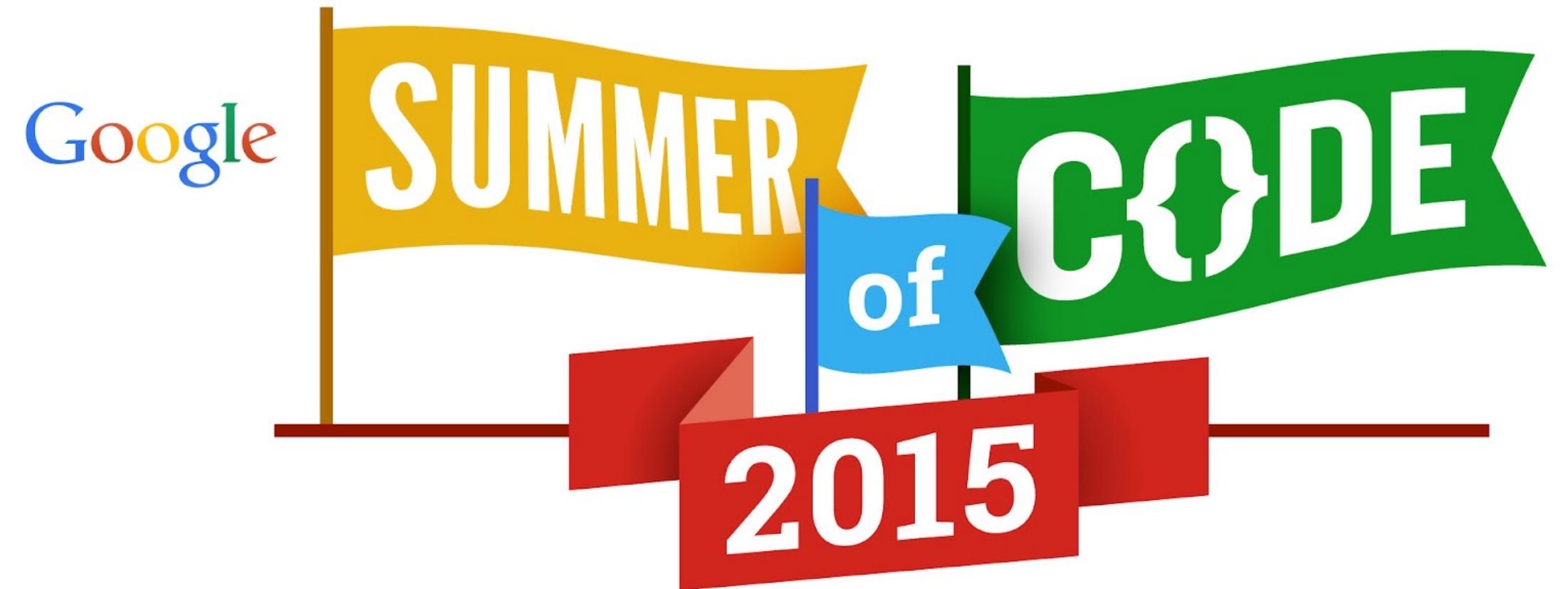
# Postgres 13: faster VACUUM

- Physically-ordered scan
- Actual page deletion

# New gist vacuum

[Edit](#) [Comment/Review ▾](#) [Change Status ▾](#)

Title	New gist vacuum
Topic	Performance
Created	2015-09-14 11:36:00
Last modified	2018-02-25 13:56:56 (5 years, 3 months ago)
Latest email	2018-03-02 17:00:41 (5 years, 2 months ago)
Status	<a href="#">2016-01</a> : <span style="background-color: red; color: white; border-radius: 5px; padding: 2px 5px;">Returned with feedback</span> <a href="#">2015-11</a> : <span style="background-color: orange; border-radius: 5px; padding: 2px 5px;">Moved to next CF</span>
Target version	
Authors	Constantine Kuznetsov (chapaev28)
Reviewers	Jeff Janes (jjanes)
Committer	Fedor Sigaev (sigaev)
Links	<a href="#">Wiki</a>
Emails	<a href="#">New gist vacuum.</a> <span style="color: grey;">×</span> First at <a href="#">2015-09-10 22:52:30</a> by Костя Кузнецов <chapaev28 at ya.ru> Latest at <a href="#">2018-03-02 17:00:41</a> by Andrey Borodin <x4mmm at yandex-team.ru> Latest attachment ( <a href="#">0001-Fix-GiST-stats-for-partial-indexes-v3.patch</a> ) at <a href="#">2018-03-02 05:33:40</a> from Andrey Borodin <x4mmm at yandex-team.ru> <span style="border: 1px solid #ccc; padding: 2px 5px; border-radius: 5px;">+</span>





# GiST VACUUM

[Edit](#) [Comment/Review ▾](#) [Change Status ▾](#)

<b>Title</b>	GiST VACUUM
<b>Topic</b>	Performance
<b>Created</b>	2018-03-07 07:42:52
<b>Last modified</b>	2019-03-25 16:34:02 (4 years, 2 months ago)
<b>Latest email</b>	2019-04-05 05:39:19 (4 years, 1 month ago)
<b>Status</b>	<a href="#">2019-03: Committed</a> <a href="#">2019-01: Moved to next CF</a> <a href="#">2018-11: Moved to next CF</a> <a href="#">2018-09: Moved to next CF</a> <a href="#">2018-07: Moved to next CF</a>
<b>Target version</b>	<a href="#">12</a>
<b>Authors</b>	Constantine Kuznetsov (chapaev28), Andrey Borodin (x4m)
<b>Reviewers</b>	Heikki Linnakangas (heikki)
<b>Committer</b>	Heikki Linnakangas (heikki)



**From:** Jeff Janes <jeff(dot)janes(at)gmail(dot)com>  
**To:** Heikki Linnakangas <hlinnaka(at)iki(dot)fi>  
**Cc:** Andrey Borodin <x4mmm(at)yandex-team(dot)ru>, Michael Paquier <michael(at)paqui.ru>  
Кузнецов <chapaev28(at)ya(dot)ru>  
**Subject:** Re: GiST VACUUM  
**Date:** 2019-03-15 19:20:06  
**Message-ID:** [CAMkU=1wOqJgjXMfO\\_R\\_rUjZ6dvba3x-xeCPBLYQZ1pTV1utLow@mail.gmail.com](mailto:CAMkU=1wOqJgjXMfO_R_rUjZ6dvba3x-xeCPBLYQZ1pTV1utLow@mail.gmail.com)  
**Views:** [Raw Message](#) | [Whole Thread](#) | [Download mbox](#) | [Resend email](#)  
**Lists:** [pgsql-hackers](#)

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On Tue, Mar 5, 2019 at 8:21 AM Heikki Linnakangas <hlinnaka(at)iki(dot)fi> wrote:

Thank you. This is a **transformational change**; it will allow GiST indexes larger than RAM to be used in some cases where they were simply not feasible to use before. On a HDD, it resulted in a 50 fold improvement in vacuum time, and the machine went from unusably unresponsive to merely sluggish during the vacuum. On a SSD (albeit a very cheap laptop one, and exposed from Windows host to Ubuntu over VM Virtual Box) it is still a 30 fold improvement, from a far faster baseline. Even on an AWS instance with a "GP2" SSD volume, which normally shows little benefit from sequential reads, I get a 3 fold speed up.

I also ran this through a lot of crash-recovery testing using simulated torn-page writes using my traditional testing harness with high concurrency (AWS c4.4xlarge and a1.4xlarge using 32 concurrent update processes) and did not encounter any problems. I tested both with btree\_gist on a scalar int, and on tsvector with each tsvector having 101 tokens.

I did notice that the space freed up in the index by vacuum doesn't seem to get re-used very efficiently, but that is an ancestral problem independent of this change.

Cheers,

Jeff

✓ **Fix data loss on crash after sorted GiST index build.**

If a checkpoint happens during sorted GiST index build, and the system crashes after the checkpoint and after the index build has finished, the data written to the index before the checkpoint started could be lost. The checkpoint won't fsync it, and it won't be replayed at crash recovery either. Fix by calling smgrimmedsync() after the index build, just like in B-tree index build.

Backpatch to v14 where the sorted GiST index build was introduced.

Reported-by: Melanie Plageman

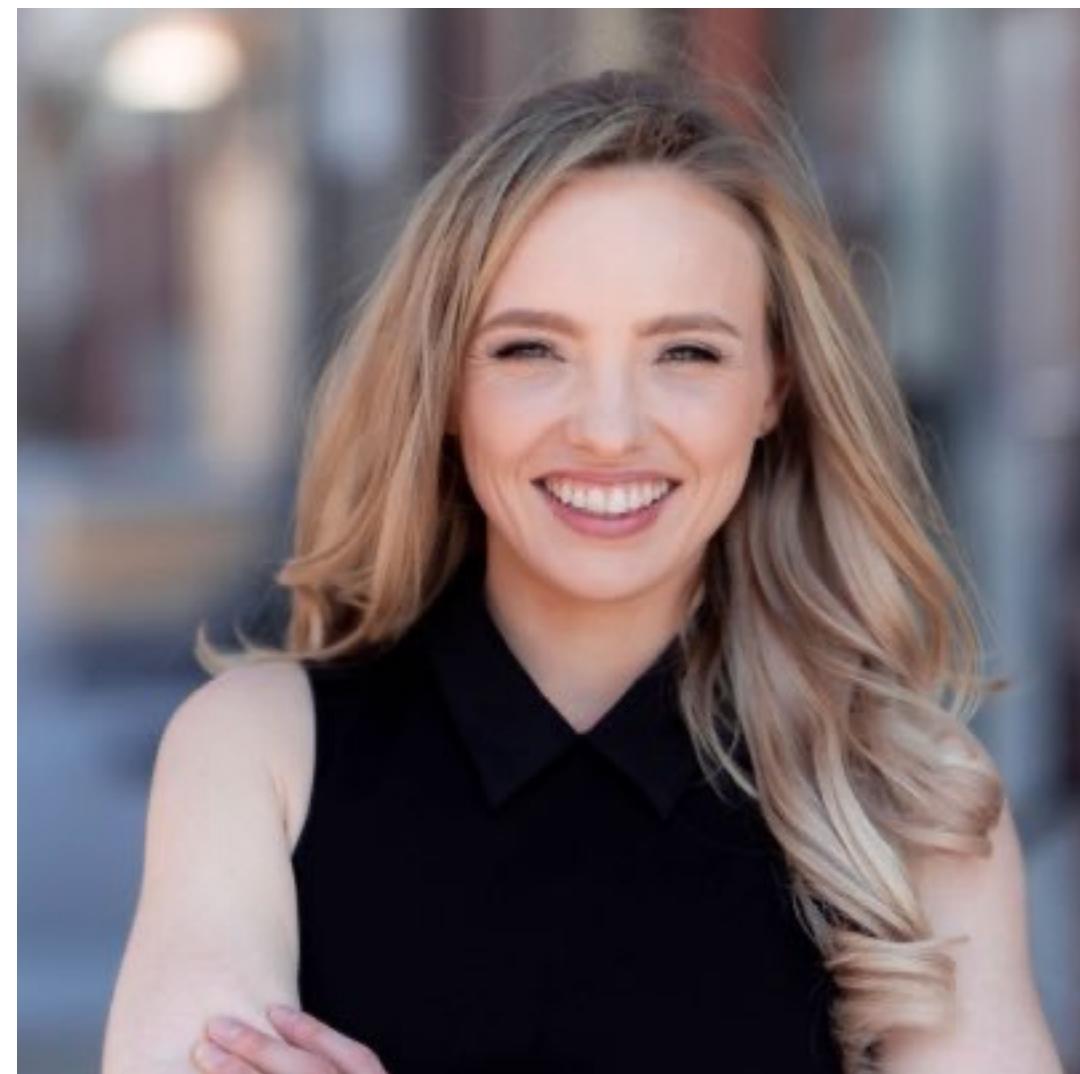
Discussion: [https://www.postgresql.org/message-id/CAAKRu\\_ZJJynimxKj5xYBSzi](https://www.postgresql.org/message-id/CAAKRu_ZJJynimxKj5xYBSzi)

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⌚ master

🏷️ REL\_16\_BETA1 ... REL\_15\_BETA1

HLINNAKA commited on Feb 24, 2022



# PostGIS hacky hacks by Komzpa



# GiST penalty for geometry

```
431 + #ifdef ADVANCED_PENALTY
432 + static float
433 + pack_float(const float value, const int realm)
434 + {
435 +     union {
436 +         float f;
437 +         struct { unsigned value:31, sign:1; } vbits;
438 +         struct { unsigned value:29, realm:2, sign:1; } rbits;
439 +     } a;
440
441 +     a.f = value;
442 +     a.rbits.value = a.vbits.value >> 2;
443 +     a.rbits.realm = realm;
444 +
445 +     return a.f;
446 + }
447 + #endif
```

gist\_btree\_bui... ▾

-o Commits on Feb 14, 2019

**Add Z-order curve functions for points and boxes**

Nikita Glukhov committed on Feb 14, 2019

**Compress GiST attributes before B-Tree sort**

Nikita Glukhov committed on Feb 14, 2019

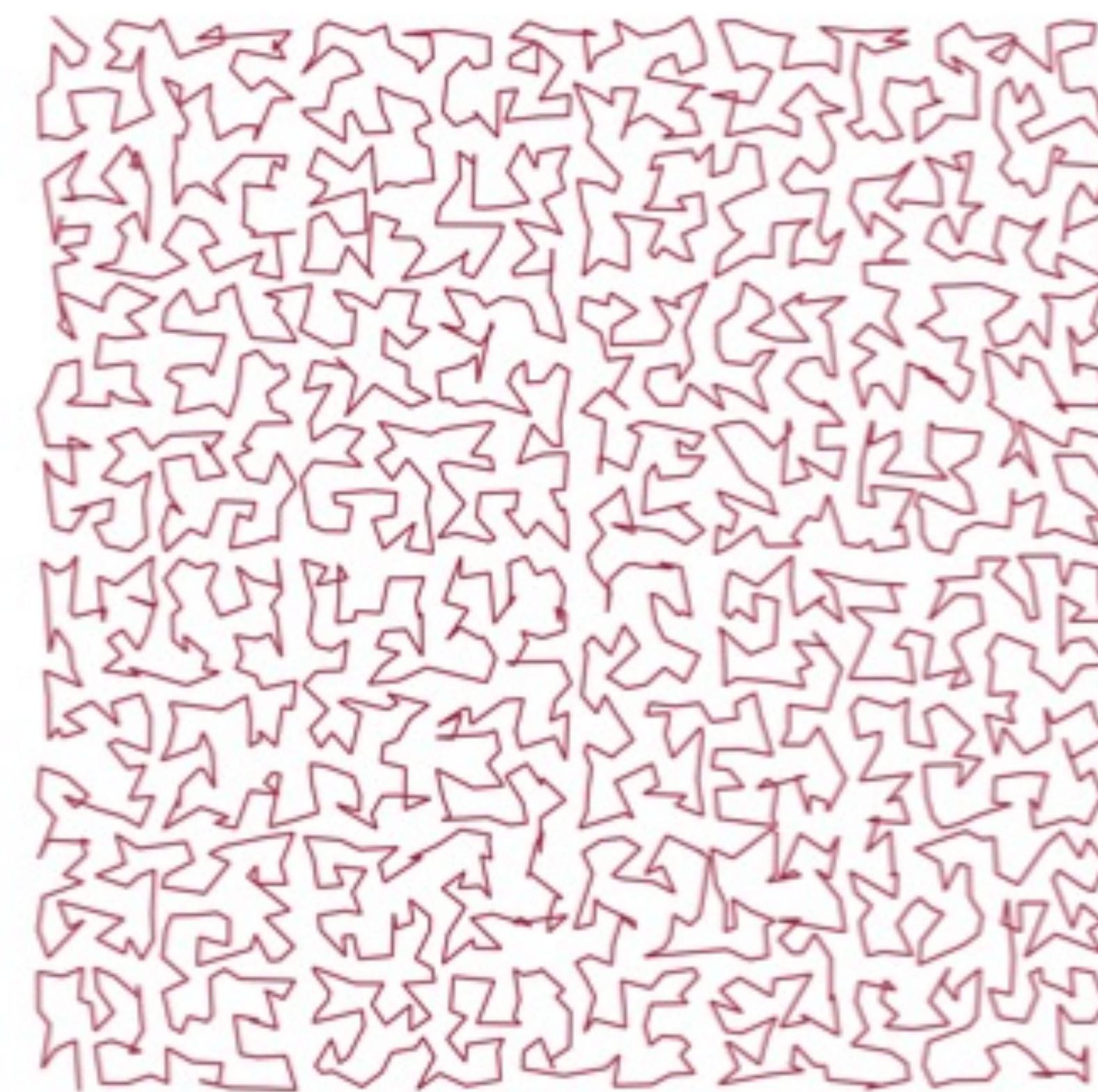
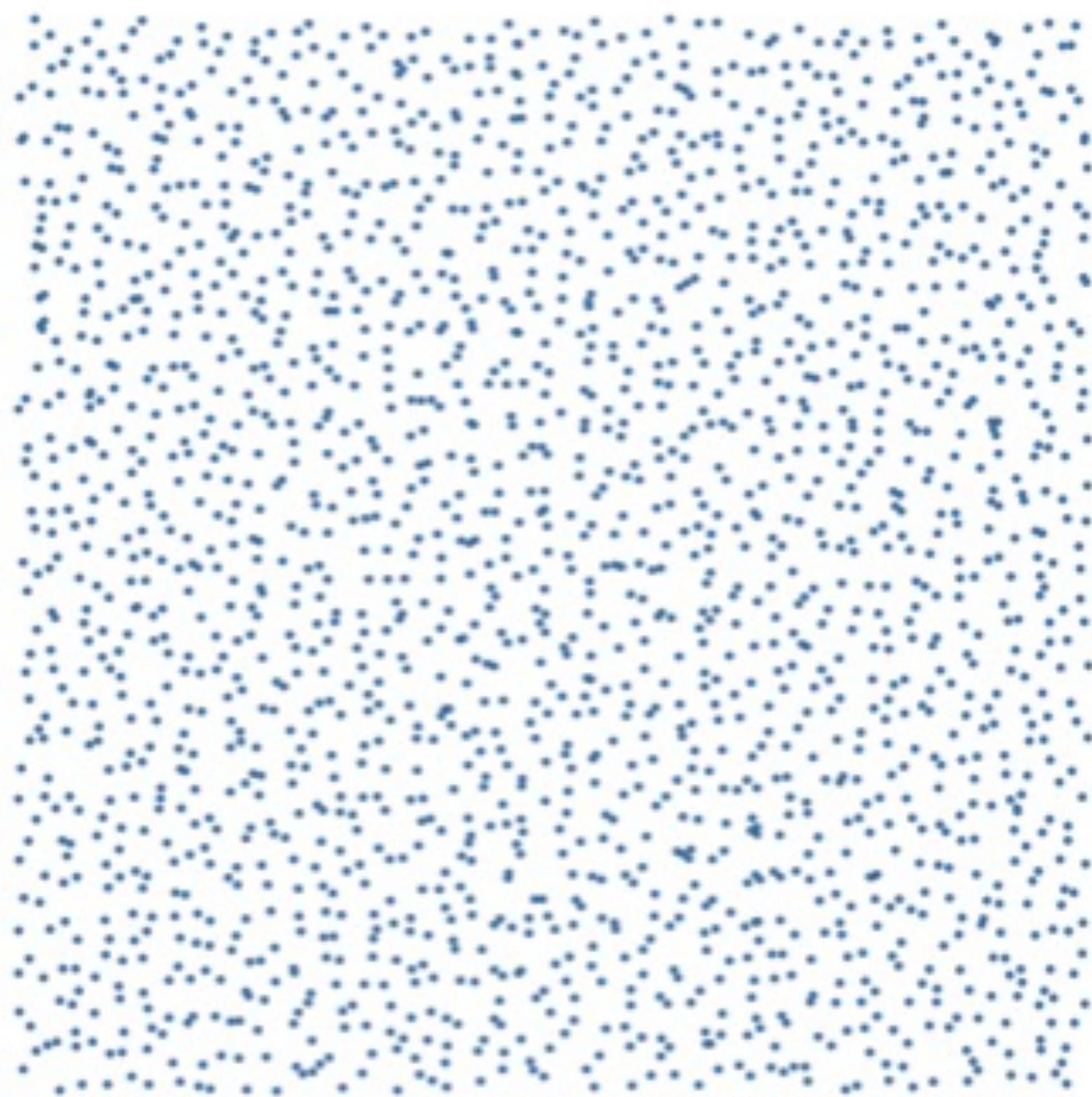
**Build GiST index as B-Tree**

Nikita Glukhov committed on Feb 14, 2019

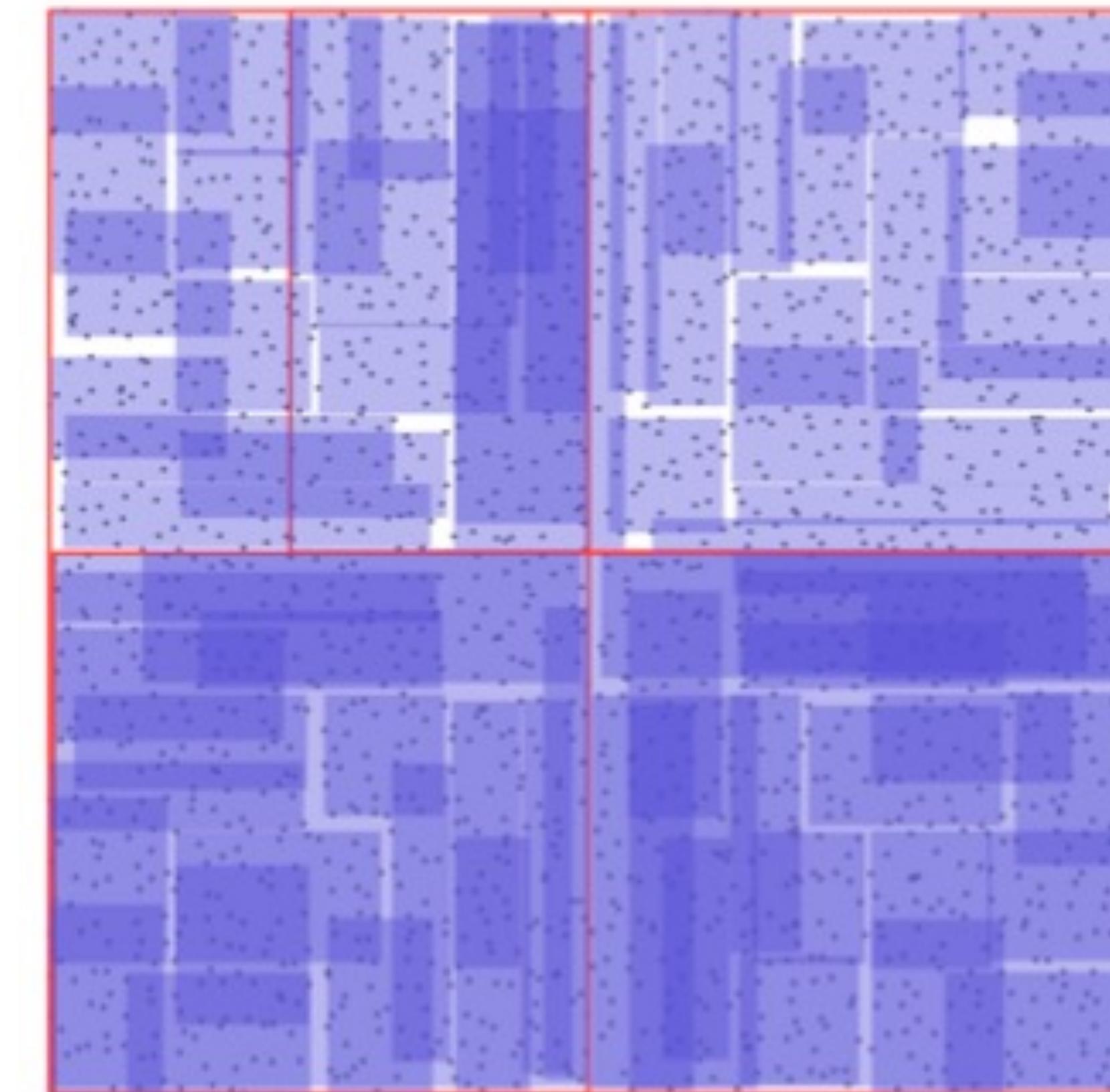
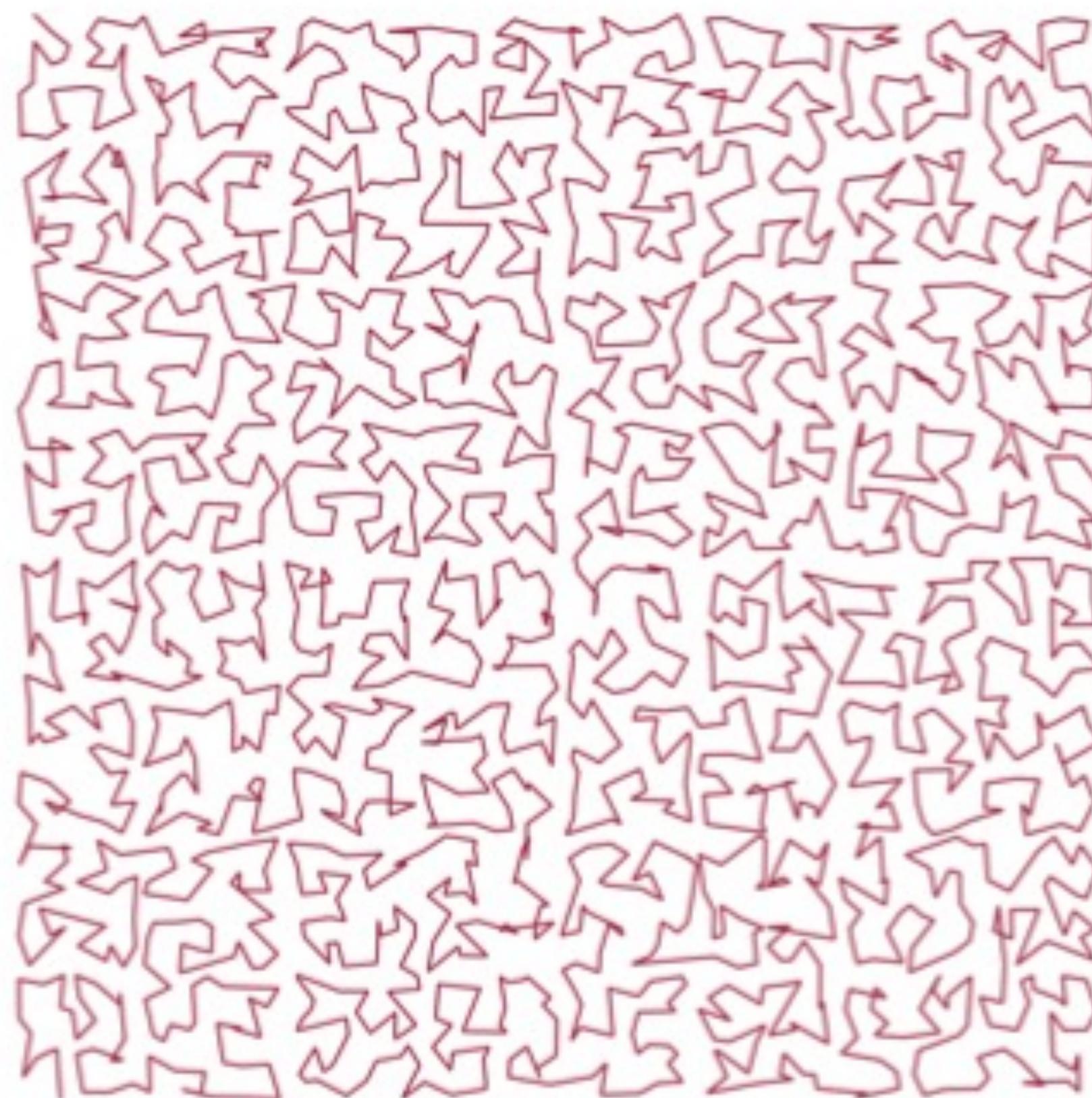


```
27  /*
28   * amproc indexes for GiST indexes.
29   */
30  #define GIST_CONSISTENT_PROC          1
31  #define GIST_UNION_PROC               2
32  #define GIST_COMPRESS_PROC            3
33  #define GIST_DECOMPRESS_PROC          4
34  #define GIST_PENALTY_PROC             5
35  #define GIST_PICKSPLIT_PROC           6
36  #define GIST_EQUAL_PROC               7
37  #define GIST_DISTANCE_PROC            8
38  #define GIST_FETCH_PROC                9
39  #define GIST_OPTIONS_PROC              10
40  #define GIST_SORTSUPPORT_PROC          11
41  #define GISTNProcs                   11
42
```

# Sorting using Hilbert curve



# Filling pages by sorted tuples



```
create index roads_rdr_idx on roads_rdr using gist(geom);  
PG14 / WITH SORTSUPPORT / CREATE 200 ms  
PG14 / NO SORTSUPPORT / CREATE 1705 ms
```

```
select pg_relation_size('roads_rdr_idx');  
PG14 / WITH SORTSUPPORT / IDXSIZE 2940928 kb  
PG14 / NO SORTSUPPORT / IDXSIZE 5439488 kb
```

```
select count(*) from roads_rdr a, roads_rdr b where a.geom && b.geom;  
PG14 / WITH SORTSUPPORT / QUERY 11200 ms  
PG14 / NO SORTSUPPORT / QUERY 4700 ms
```

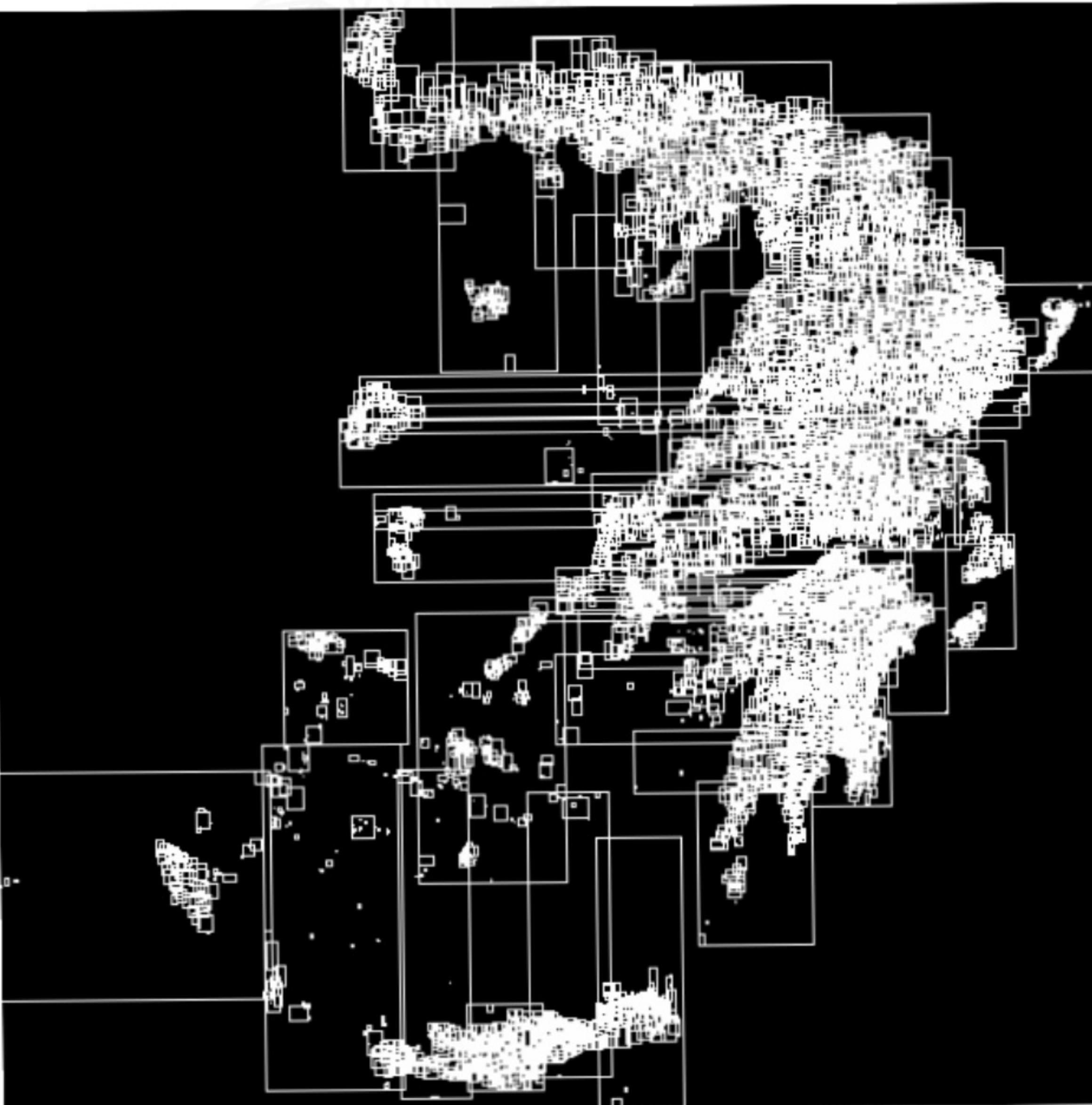
# GiST sorting build

		<a href="#">Edit</a> <a href="#">Comment/Review ▾</a> <a href="#">Change Status ▾</a>
<b>Title</b>	GiST sorting build	
<b>Topic</b>	Server Features	
<b>Created</b>	2019-09-02 05:36:43	
<b>Last modified</b>	2020-11-05 16:15:23 (2 years, 6 months ago)	
<b>Latest email</b>	2021-12-16 09:18:52 (1 year, 5 months ago)	
<b>Status</b>	<p>2020-09: <span>Committed</span></p> <p>2020-07: <span>Moved to next CF</span></p> <p>2020-03: <span>Moved to next CF</span></p> <p>2020-01: <span>Moved to next CF</span></p> <p>2019-11: <span>Moved to next CF</span></p>	
<b>Target version</b>		
<b>Authors</b>	Andrey Borodin (x4m)	
<b>Reviewers</b>	Heikki Linnakangas (heikki), Pavel Borisov (pborisov)	
<b>Committer</b>	Heikki Linnakangas (heikki)	

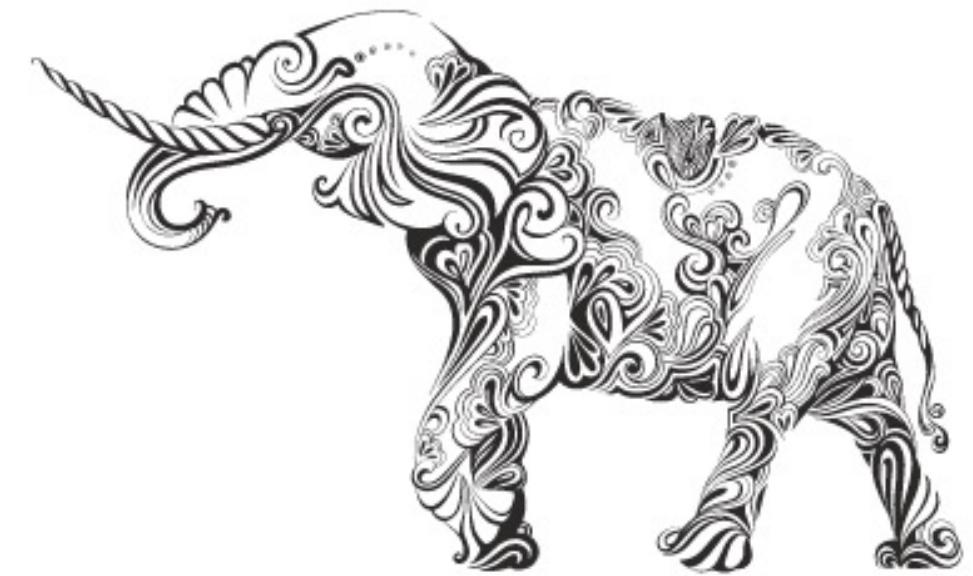


# Building gist by default GiST

- › PG 13- : buffered build
- › PG 14+ : sorted build
- › PostGIS 3.2 adds sorted build for 2D geometry



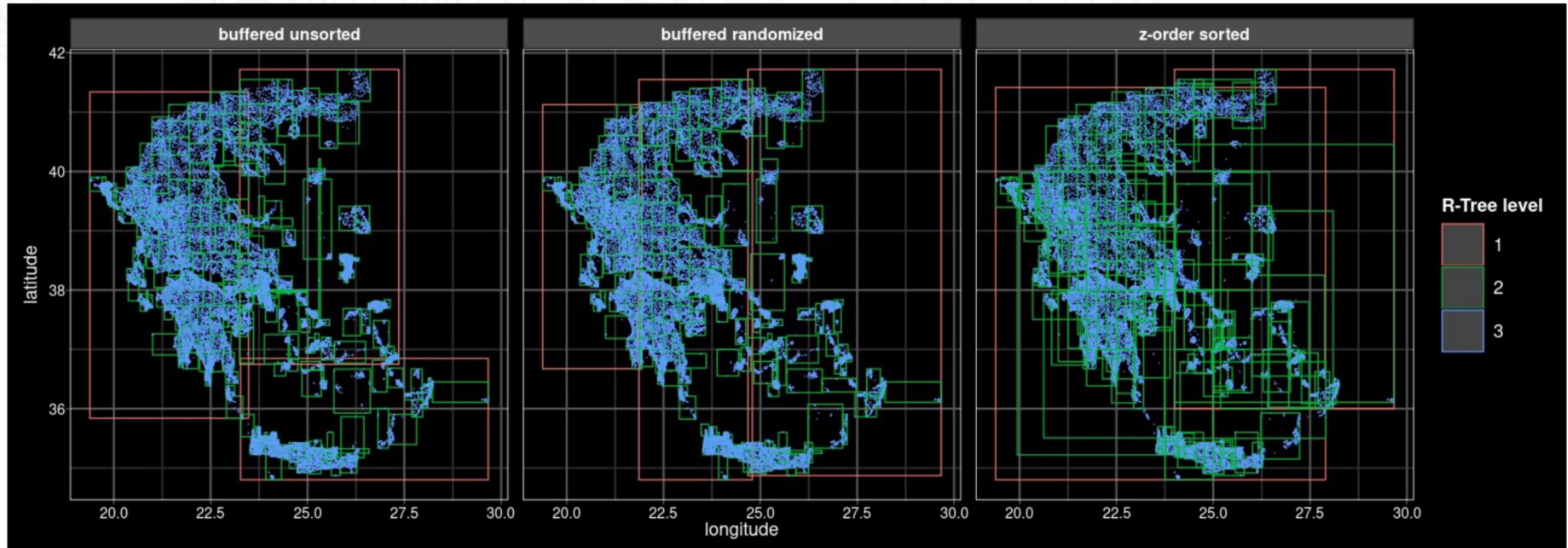
# K-Nearest Neighbors Search in PostgreSQL



Oleg Bartunov, Nikita Glukhov  
Postgres Professional

# Example: GiST R-Tree for Greece

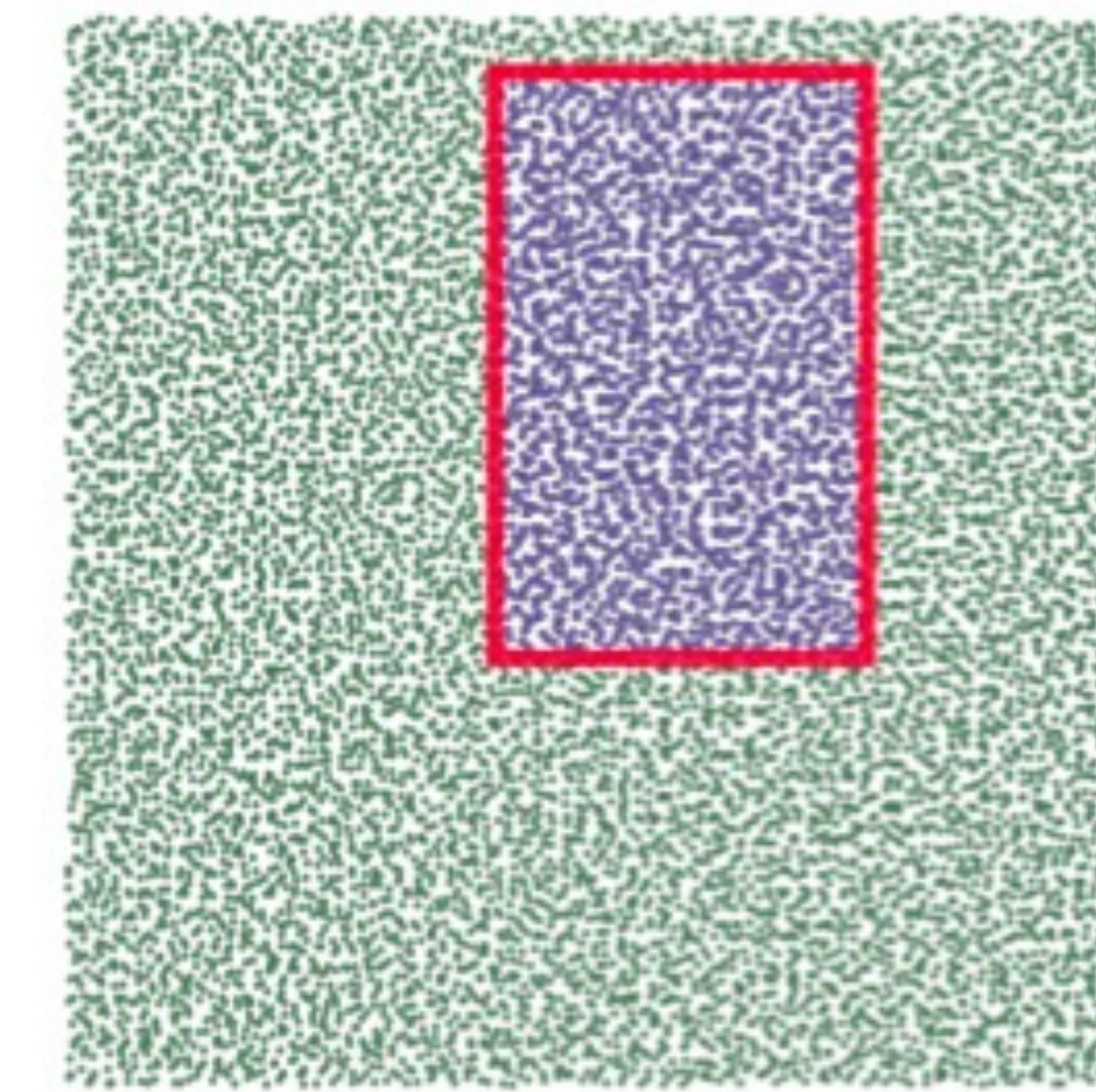
Z-order index boxes overlaps more strongly



# What's the problem of a sorted build?



Level 1

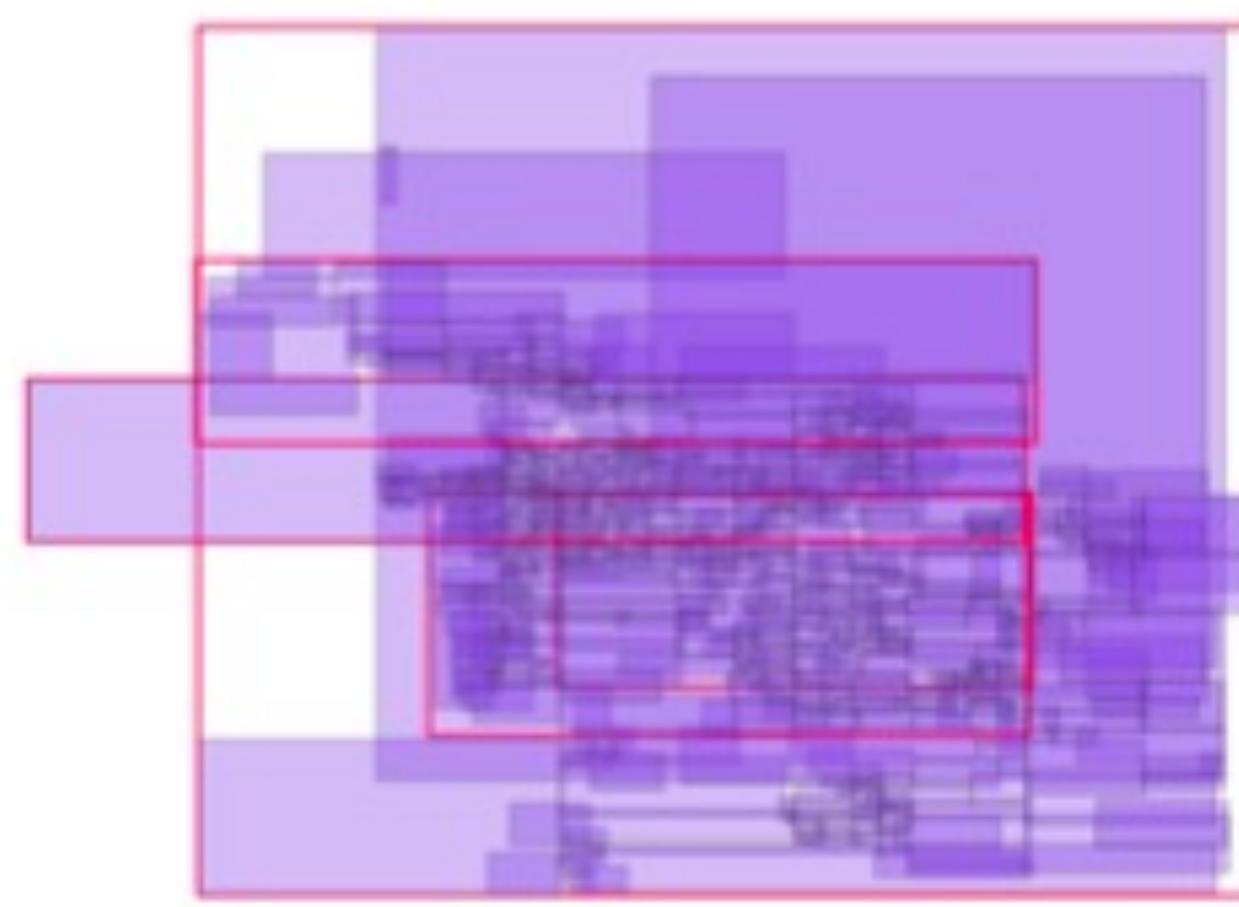


Level 2

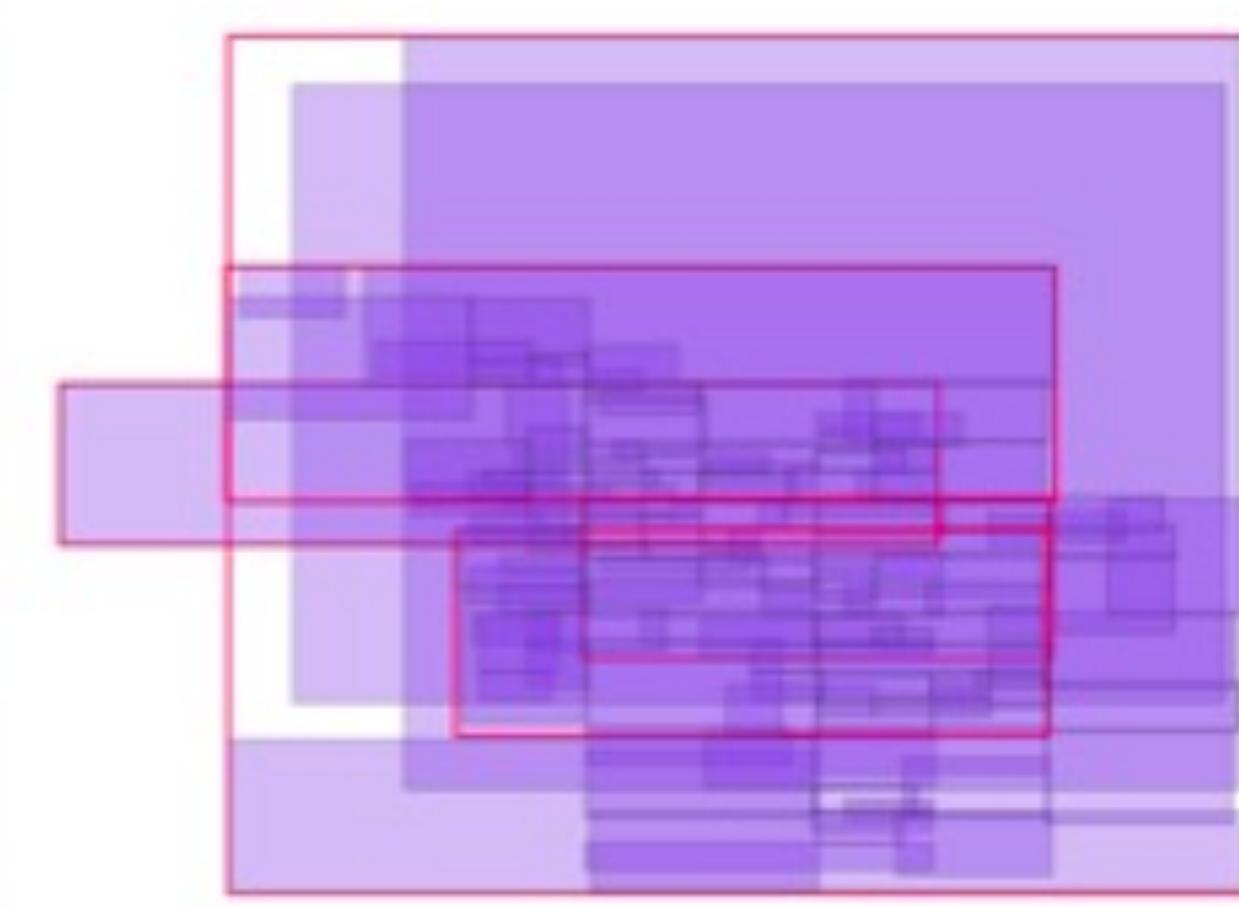
# fillfactor



fillfactor = 100  
self-join = 3120.143 ms  
index size = 2.6 mb



fillfactor = 50  
self-join = 2346.177 ms  
index size = 5.3 mb



fillfactor = 10  
self-join = 1019.454 ms  
index size = 29.2 mb

# What's the problem of a sorted build?

| **We use neither Split() nor Penalty() from opclass**

# New algorithm with Split()

	<b>SORT SUPPORT (PG14)</b>	<b>SORT SUPPORT (PG15)</b>	<b>NO SORT SUPPORT</b>
<b>CREATE INDEX</b>	51.2429	165.6421	273.2494
<b>SELECT, SELF-JOIN</b>	4100.5645	1752.5885	1709.3702
<b>SELECT, TILING</b>	458.5242	418.7391	424.466
<b>SELECT, KNN (K = 1)</b>	401.8068	242.7706	248.6685
<b>SIZE OF INDEX (MB)</b>	2.940928	4.95616	5.496832

# Small nuance

```
#define GIST_SORTED_BUILD_PAGE_NUM 4
```



## **New build:**

- › Available in PG 15
- › Default in PostGIS 3.3

# Postgres 15: better GiST build

reduce page overlap of GiST indexes built using sorted method

Edit Comment/Review ▾ Change Status ▾

Title	reduce page overlap of GiST indexes built using sorted method
Topic	Performance
Created	2021-12-30 11:31:48
Last modified	2022-02-08 05:19:31 (1 year, 3 months ago)
Latest email	2022-02-04 00:52:56 (1 year, 3 months ago)
Status	<span>2022-03: Committed</span> <span>2022-01: Moved to next CF</span>
Target version	15
Authors	Sergei Shoulbakov (sshoulbakov), Andrey Borodin (x4m), Aliaksandr Kalenik (kalenik.aliaksandr@gmail.com)
Reviewers	Regina Obe (reginaobe)
Committer	Alexander Korotkov (smagen)



# TODO

# Functions for sorting GiST build of gist\_btree types

[Edit](#)[Comment/Review ▾](#)[Change Status ▾](#)

<b>Title</b>	Functions for sorting GiST build of gist_btree types
<b>Topic</b>	Miscellaneous
<b>Created</b>	2020-11-05 16:09:37
<b>Last modified</b>	2022-04-08 15:16:25 (1 year, 1 month ago)
<b>Latest email</b>	2021-12-16 09:18:52 (1 year, 5 months ago)
<b>Status</b>	<p>2022-03: <span style="background-color: red; border-radius: 5px; padding: 2px 5px;">Returned with feedback</span></p> <p>2022-01: <span style="background-color: orange; border-radius: 5px; padding: 2px 5px;">Moved to next CF</span></p> <p>2021-11: <span style="background-color: orange; border-radius: 5px; padding: 2px 5px;">Moved to next CF</span></p> <p>2021-09: <span style="background-color: orange; border-radius: 5px; padding: 2px 5px;">Moved to next CF</span></p> <p>2021-07: <span style="background-color: orange; border-radius: 5px; padding: 2px 5px;">Moved to next CF</span></p> <p>2021-03: <span style="background-color: orange; border-radius: 5px; padding: 2px 5px;">Moved to next CF</span></p> <p>2021-01: <span style="background-color: orange; border-radius: 5px; padding: 2px 5px;">Moved to next CF</span></p>
<b>Target version</b>	
<b>Authors</b>	Andrey Borodin (x4m)
<b>Reviewers</b>	Heikki Linnakangas (heikki), Emre Hasegeli (hasegeli)
<b>Committer</b>	Heikki Linnakangas (heikki)

# Add sortsupport for range types and btree\_gist

[Edit](#)[Comment/Review ▾](#)[Change Status ▾](#)

<b>Title</b>	Add sortsupport for range types and btree_gist
<b>Topic</b>	Performance
<b>Created</b>	2022-06-15 10:46:24
<b>Last modified</b>	2023-04-09 03:21:36 (1 month, 3 weeks ago)
<b>Latest email</b>	2022-11-30 17:25:25 (6 months ago)
<b>Status</b>	<a href="#">2023-07: Needs review</a> <a href="#">2023-03: Moved to next CF</a> <a href="#">2023-01: Moved to next CF</a> <a href="#">2022-11: Moved to next CF</a> <a href="#">2022-09: Moved to next CF</a> <a href="#">2022-07: Moved to next CF</a>
<b>Target version</b>	
<b>Authors</b>	Christoph Heiss (christoph.heiss)
<b>Reviewers</b>	Bernd Helmle (psoo)
<b>Committer</b>	



# Amcheck verification of GiST and GIN

		<a href="#">Edit</a>	<a href="#">Comment/Review ▾</a>	<a href="#">Change Status ▾</a>
<b>Title</b>	Amcheck verification of GiST and GIN			
<b>Topic</b>	Monitoring & Control			
<b>Created</b>	2022-06-30 06:40:35			
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<b>Status</b>	<div><span>2023-07:</span> <span>Ready for Committer</span></div> <div><span>2023-03:</span> <span>Moved to next CF</span></div> <div><span>2023-01:</span> <span>Moved to next CF</span></div> <div><span>2022-11:</span> <span>Moved to next CF</span></div> <div><span>2022-09:</span> <span>Moved to next CF</span></div> <div><span>2022-07:</span> <span>Moved to next CF</span></div>			
<b>Target version</b>				
<b>Authors</b>	Andrey Borodin (x4m), Heikki Linnakangas (heikki), Grigory Kryachko (gskryachko)			
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# Ambitious ideas

- Spatial Join (pg\_sphere-like)
- Better GiST API (to suite RR\*-tree index)
- Intra-page indexing (to match B-tree performance)
- Move GiST to contrib (needs improved generic WAL)

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Open source software is  
made and maintained  
by people, for people

# Thank you for working on Postgres!



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