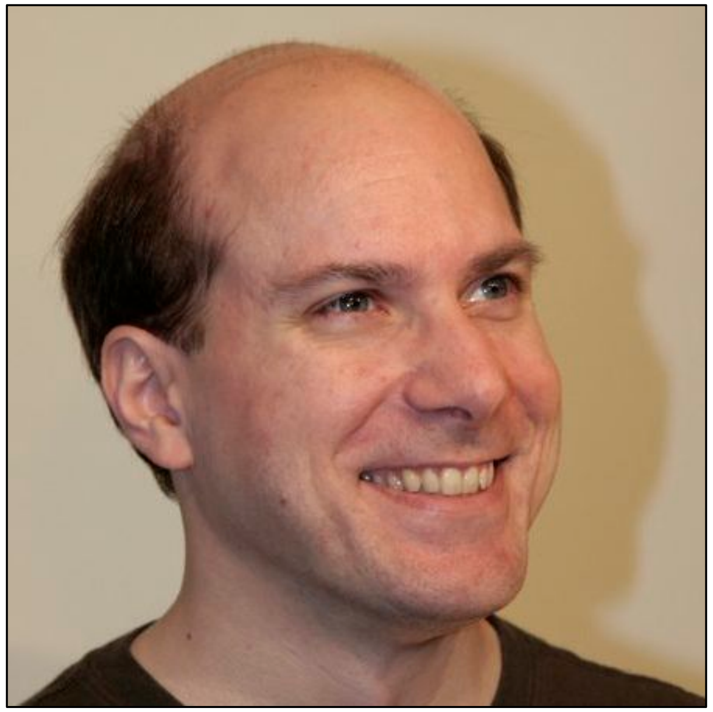
# Models for Hierarchical Data with SQL and PHP

Bill Karwin, Percona Inc.

# Me

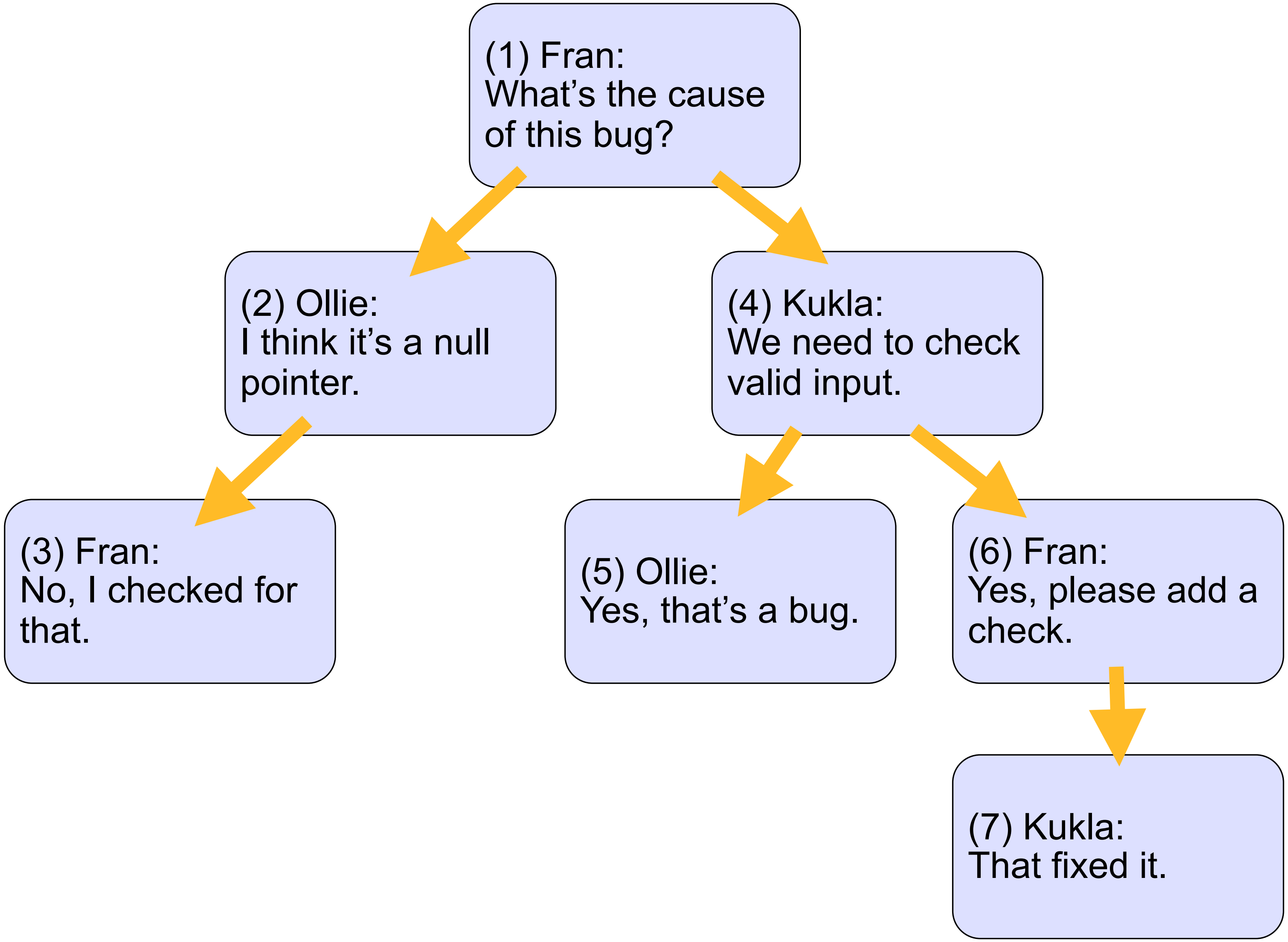
- Software developer
- C, Java, Perl, PHP, Ruby
- SQL maven
- MySQL Consultant at Percona
- Author of *SQL Antipatterns: Avoiding the Pitfalls of Database Programming*



# Problem

- Store & query hierarchical data
  - Categories/subcategories
  - Bill of materials
  - Threaded discussions

# Example: Bug Report Comments



(1) Fran:
What's the cause of this bug?

(2) Ollie:
I think it's a null pointer.

(3) Fran:
No, I checked for that.

(4) Kukla:
We need to check valid input.

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Yes, that's a bug.

(6) Fran:
Yes, please add a check.

(7) Kukla:
That fixed it.

# Solutions

- Adjacency list
- Path enumeration
- Nested sets
- Closure table

# Adjacency List

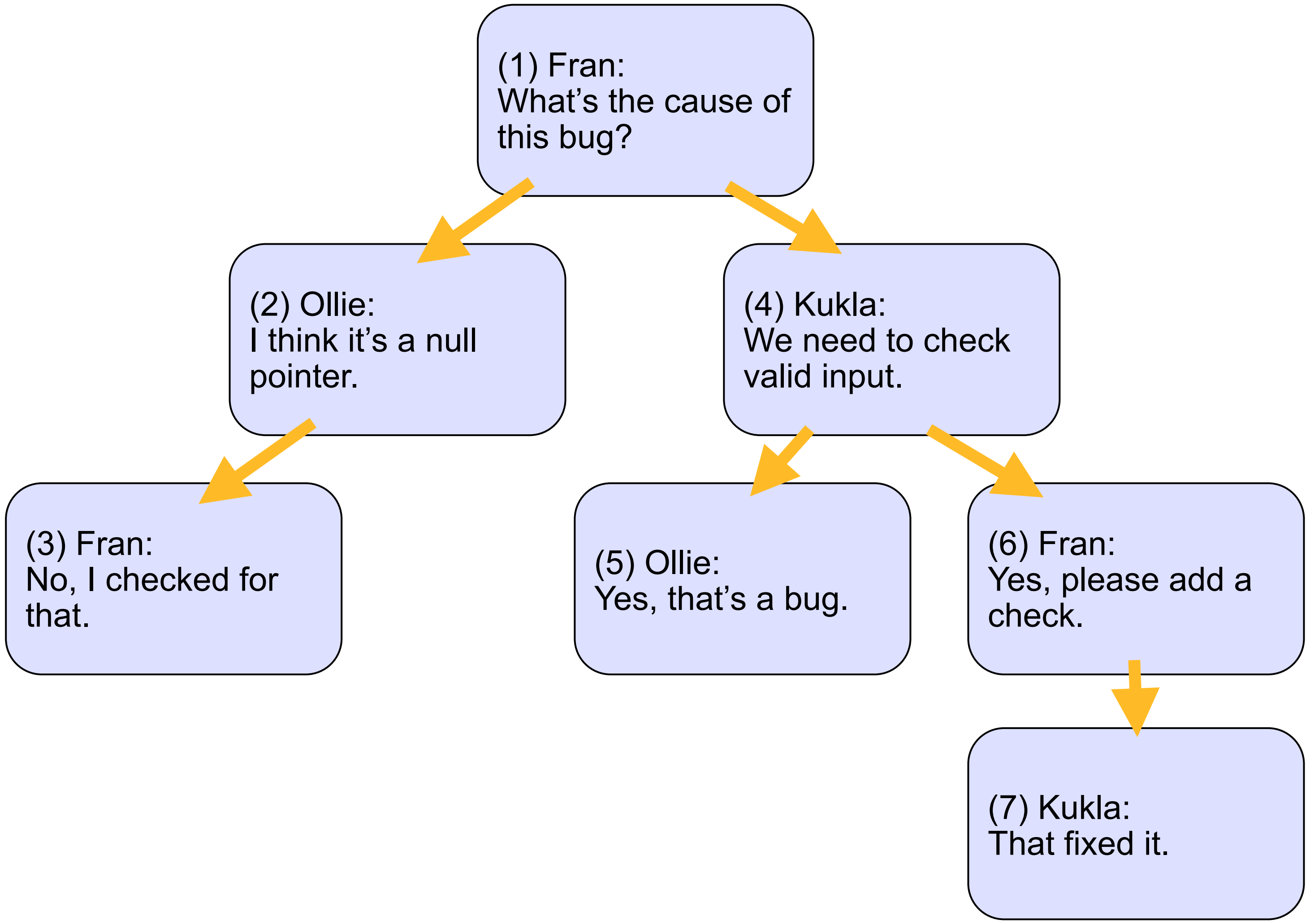
# Adjacency List

- Naive solution nearly everyone uses
- Each entry knows its immediate parent

| comment_id | parent_id | author | comment |
|---|---|---|---|
| 1 | NULL | Fran | What’s the cause of this bug? |
| 2 | 1 | Ollie | I think it’s a null pointer. |
| 3 | 2 | Fran | No, I checked for that. |
| 4 | 1 | Kukla | We need to check valid input. |
| 5 | 4 | Ollie | Yes, that’s a bug. |
| 6 | 4 | Fran | Yes, please add a check |
| 7 | 6 | Kukla | That fixed it. |

# Insert a New Node

```
INSERT INTO Comments (parent_id, author, comment)
  VALUES (5, ‘Fran’, ‘I agree!’);
```



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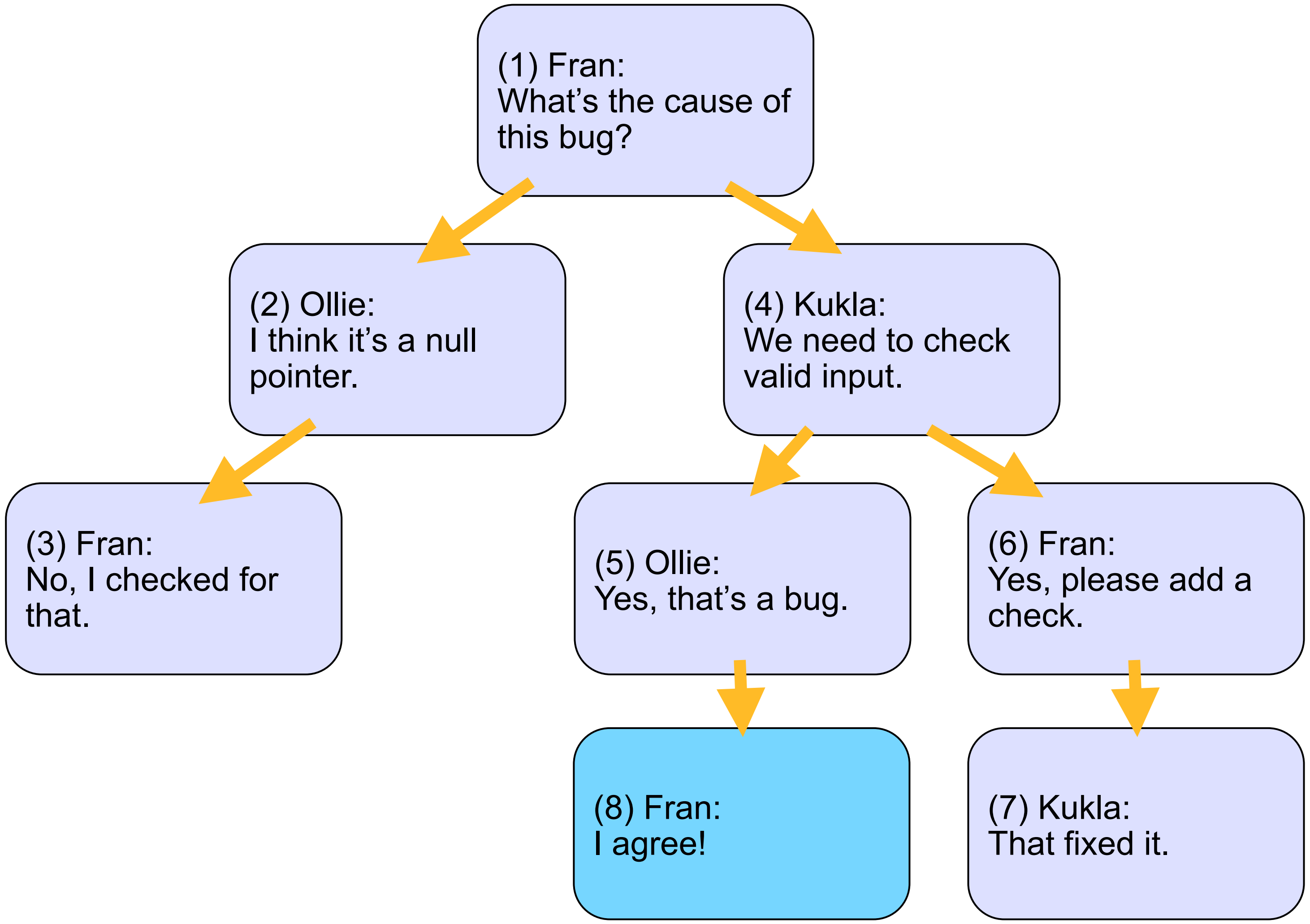
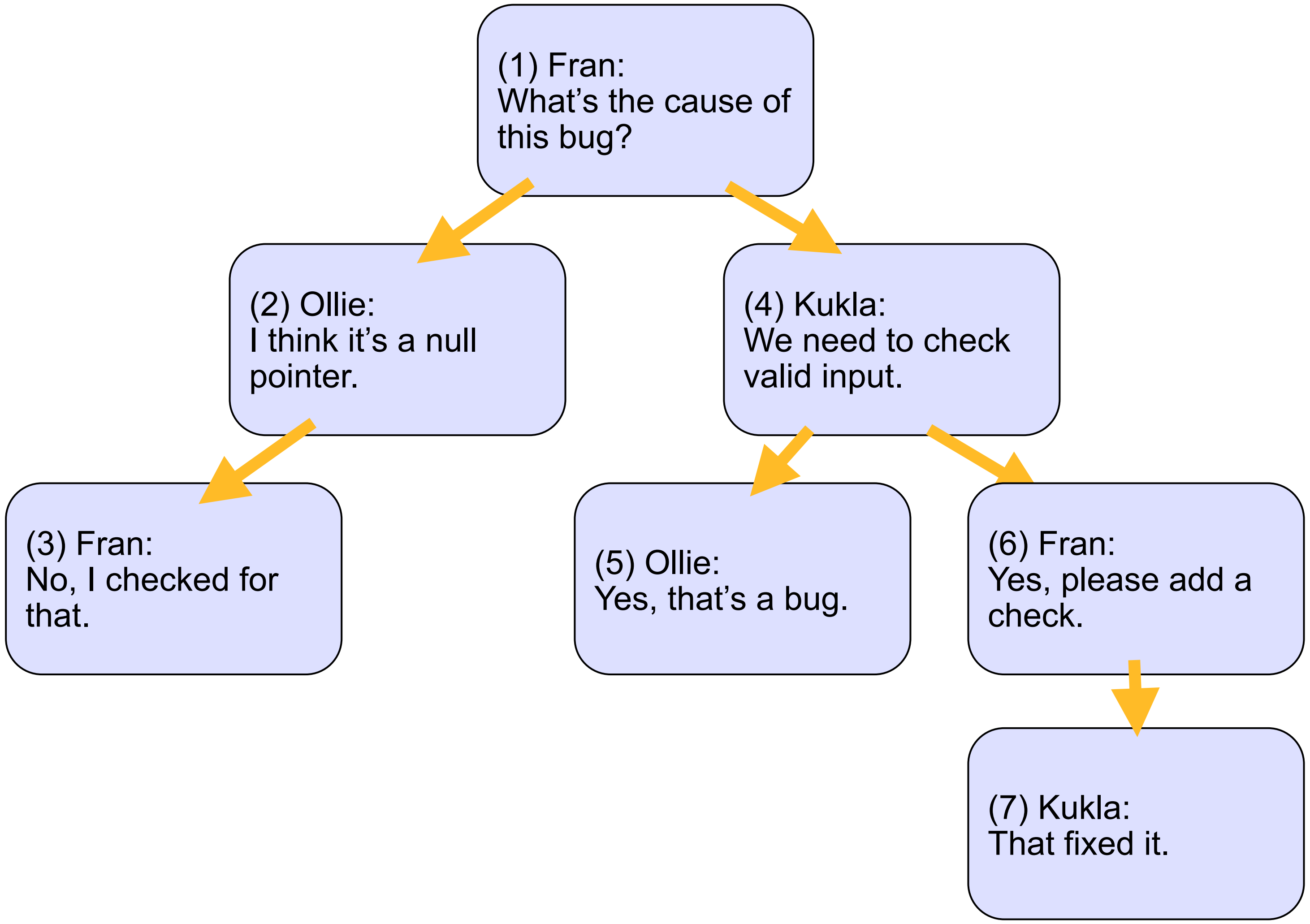


# Move a Node or Subtree

```
UPDATE Comments SET parent_id = 3
   WHERE comment_id = 6;
```



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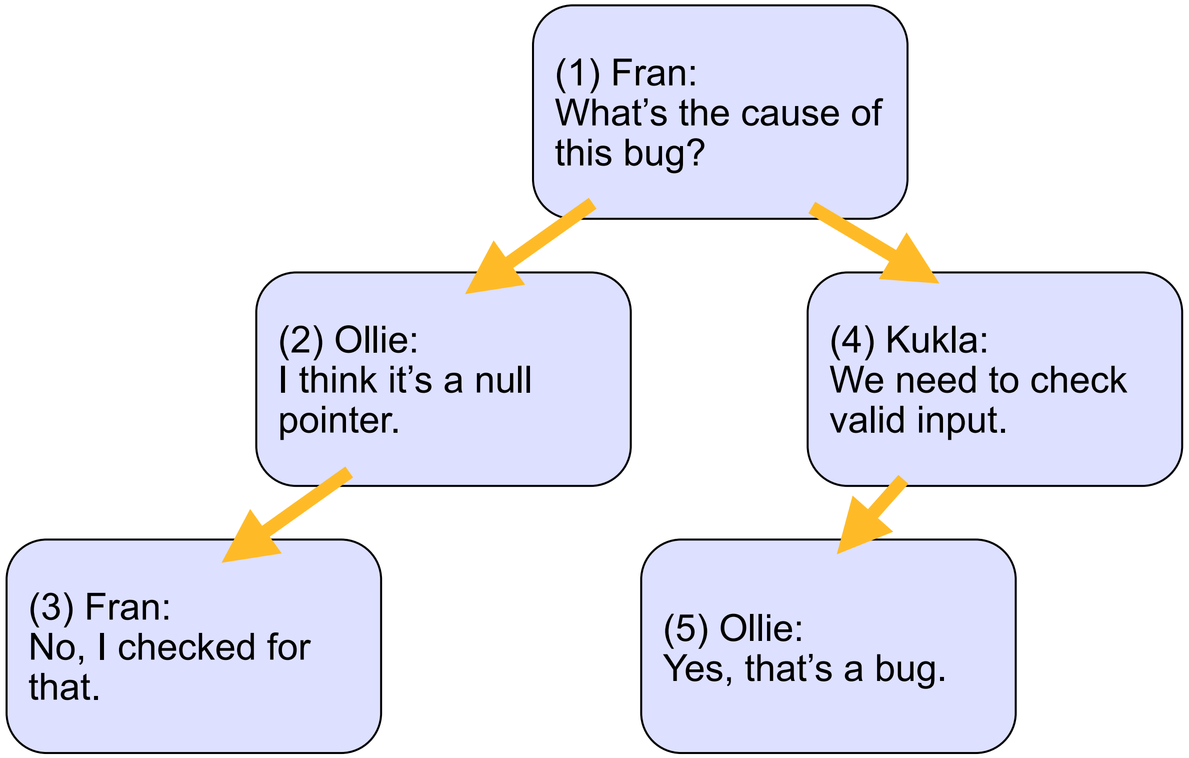

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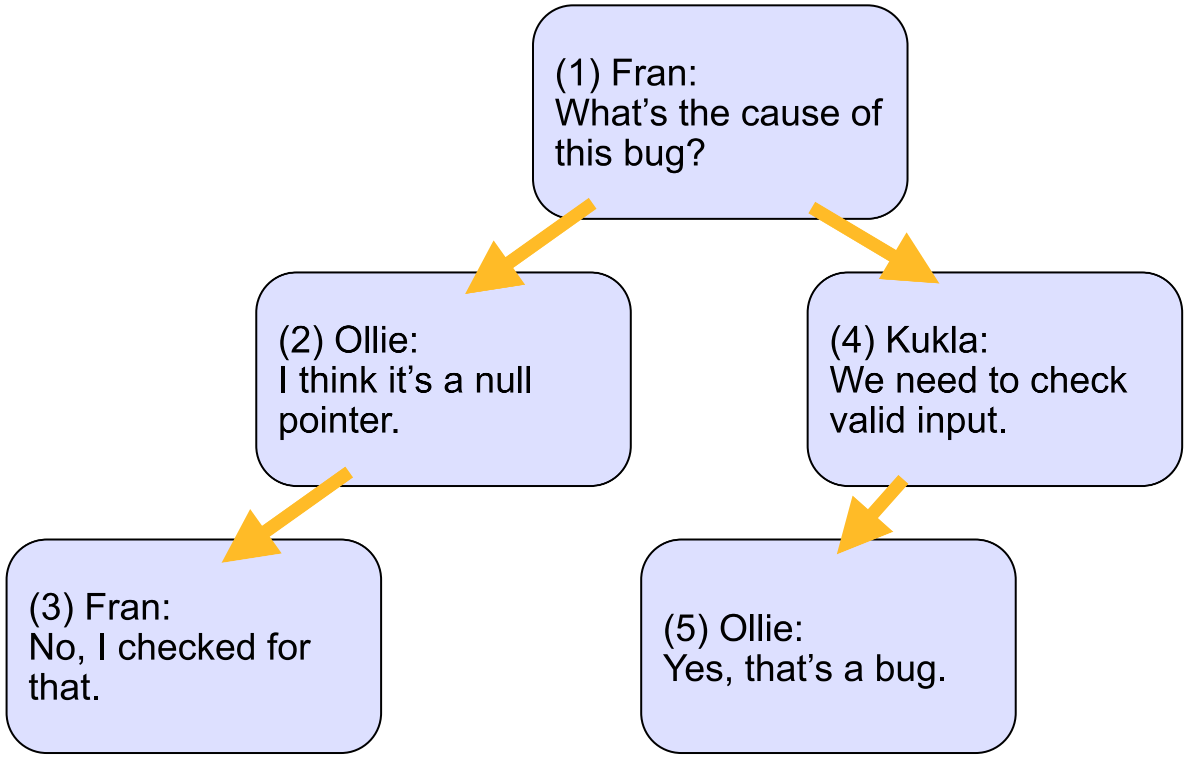
UPDATE Comments SET parent_id = 3
   WHERE comment_id = 6;
```



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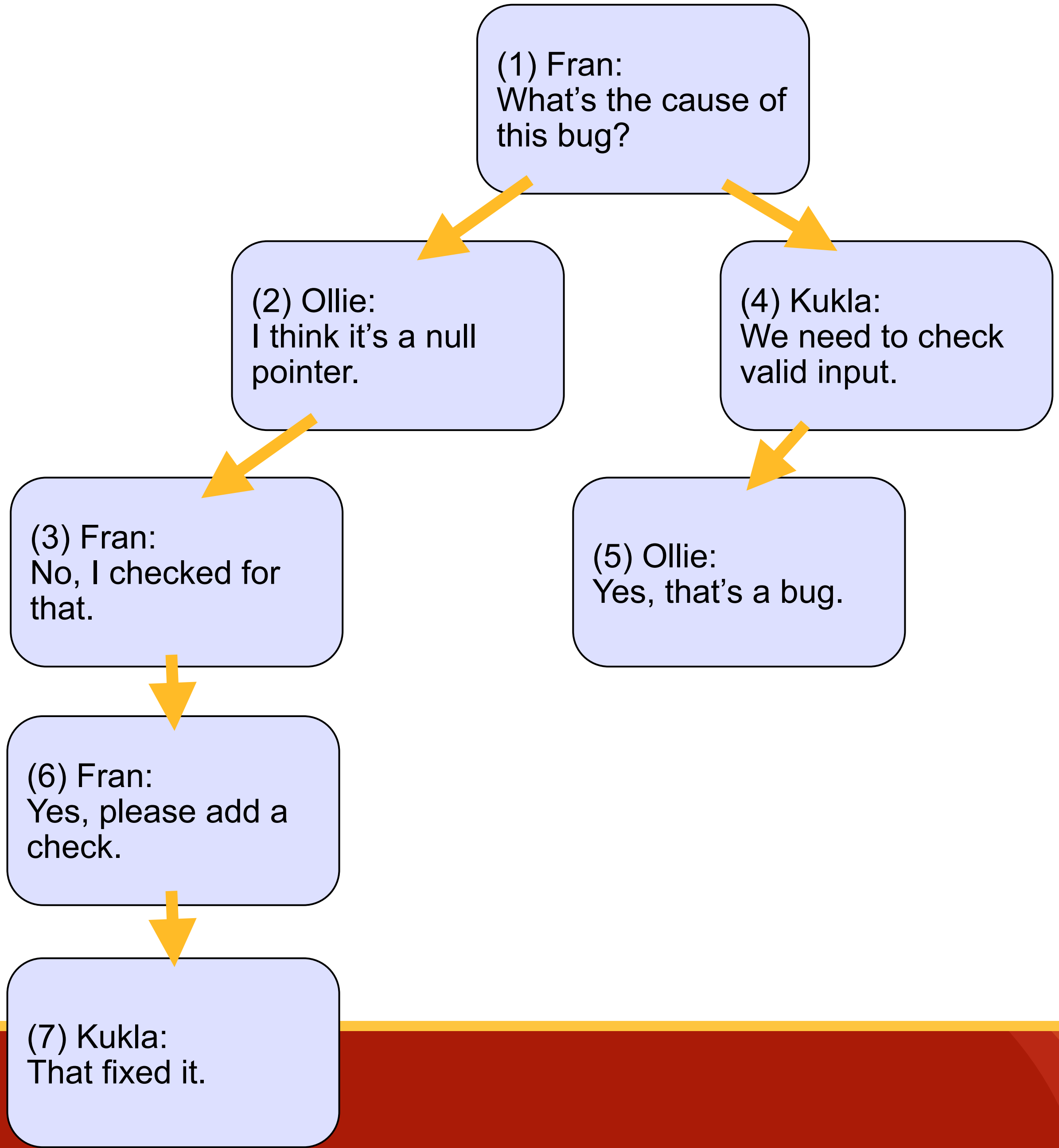

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# Query Immediate Child/Parent

- Query a node's   children:

```
SELECT * FROM Comments c1
  LEFT JOIN Comments c2
    ON (c2.parent_id = c1.comment_id);
```

- Query a node's parent:

```
SELECT * FROM Comments c1
  JOIN Comments c2
    ON (c1.parent_id = c2.comment_id);
```

# Can’t Handle Deep Trees

```
SELECT * FROM Comments c1
  LEFT JOIN Comments c2 ON (c2.parent_id = c1.comment_id)
  LEFT JOIN Comments c3 ON (c3.parent_id = c2.comment_id)
  LEFT JOIN Comments c4 ON (c4.parent_id = c3.comment_id)
  LEFT JOIN Comments c5 ON (c5.parent_id = c4.comment_id)
  LEFT JOIN Comments c6 ON (c6.parent_id = c5.comment_id)
  LEFT JOIN Comments c7 ON (c7.parent_id = c6.comment_id)
  LEFT JOIN Comments c8 ON (c8.parent_id = c7.comment_id)
  LEFT JOIN Comments c9 ON (c9.parent_id = c8.comment_id)
  LEFT JOIN Comments c10 ON (c10.parent_id = c9.comment_id)
  . . .
```

# Can’t Handle Deep Trees

```
SELECT * FROM Comments c1
  LEFT JOIN Comments c2 ON (c2.parent_id = c1.comment_id)
  LEFT JOIN Comments c3 ON (c3.parent_id = c2.comment_id)
  LEFT JOIN Comments c4 ON (c4.parent_id = c3.comment_id)
  LEFT JOIN Comments c5 ON (c5.parent_id = c4.comment_id)
  LEFT JOIN Comments c6 ON (c6.parent_id = c5.comment_id)
  LEFT JOIN Comments c7 ON (c7.parent_id = c6.comment_id)
  LEFT JOIN Comments c8 ON (c8.parent_id = c7.comment_id)
  LEFT JOIN Comments c9 ON (c9.parent_id = c8.comment_id)
  LEFT JOIN Comments c10 ON (c10.parent_id = c9.comment_id)
  . . .
```

*it still doesn’t support unlimited depth!*

# SQL-99 recursive syntax

```
WITH [RECURSIVE] CommentTree
        (comment_id, bug_id, parent_id, author, comment, depth)
   AS (
        SELECT *, 0 AS depth FROM Comments
        WHERE parent_id IS NULL
     UNION ALL
        SELECT c.*, ct.depth+1 AS depth FROM CommentTree ct
        JOIN Comments c ON (ct.comment_id = c.parent_id)
   )
   SELECT * FROM CommentTree WHERE bug_id = 1234;
```

✓ *PostgreSQL, Oracle 11g, IBM DB2, Microsoft SQL Server, Apache Derby*

✗ *MySQL, SQLite, Informix, Firebird,etc.*

# Path Enumeration

# Path Enumeration

- Store chain of ancestors in each node

| comment_id | path | author | comment |
|---|---|---|---|
| 1 | 1/ | Fran | What's the cause of this bug? |
| 2 | 1/2/ | Ollie | I think it's a null pointer. |
| 3 | 1/2/3/ | Fran | No, I checked for that. |
| 4 | 1/4/ | Kukla | We need to check valid input. |
| 5 | 1/4/5/ | Ollie | Yes, that's a bug. |
| 6 | 1/4/6/ | Fran | Yes, please add a check |
| 7 | 1/4/6/7/ | Kukla | That fixed it. |

# Path Enumeration

- Store chain of ancestors in each node

*good for breadcrumbs*

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|---|---|---|---|
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| 4 | 1/4/ | Kukla | We need to check valid input. |
| 5 | 1/4/5/ | Ollie | Yes, that's a bug. |
| 6 | 1/4/6/ | Fran | Yes, please add a check |
| 7 | 1/4/6/7/ | Kukla | That fixed it. |

# Query Ancestors and Subtrees

- Query ancestors of comment #7:

```
SELECT * FROM Comments
  WHERE ‘1/4/6/7/’ LIKE path || ‘%’;
```

- Query descendants of comment #4:

```
SELECT * FROM Comments
  WHERE path LIKE ‘1/4/%’;
```

# Add a New Child of #7

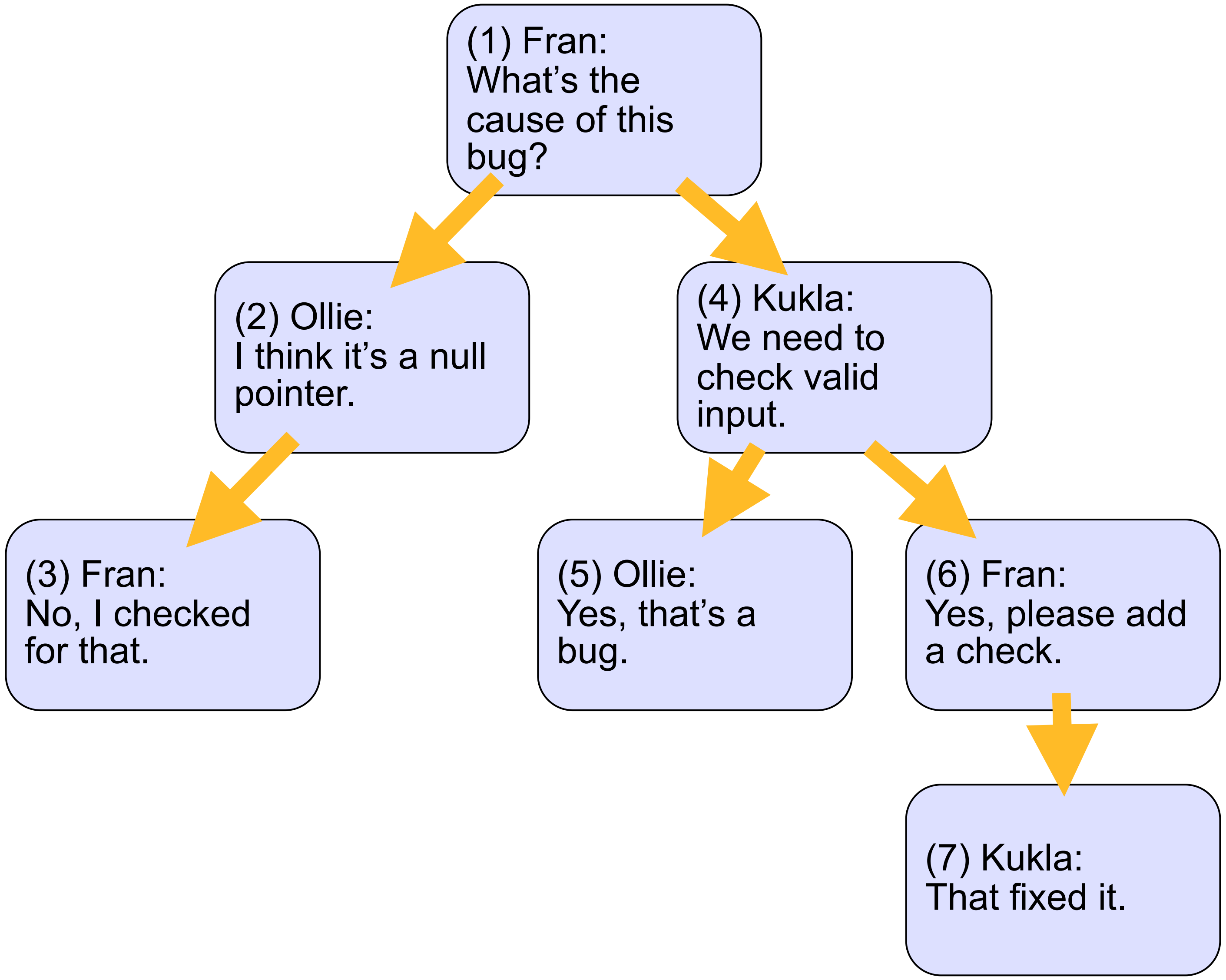
```
INSERT INTO Comments (author, comment)
   VALUES (‘Ollie’, ‘Good job!’);
SELECT path FROM Comments
   WHERE comment_id = 7;
UPDATE Comments
   SET path = $parent_path || LAST_INSERT_ID() || ‘/’
   WHERE comment_id = LAST_INSERT_ID();
```

# Nested Sets

# Nested Sets

- Each comment encodes its descendants using two numbers:
  - A comment’s ***left*** number is ***less than*** all numbers used by the comment’s descendants.
  - A comment’s ***right*** number is ***greater than*** all numbers used by the comment’s descendants.
  - A comment’s numbers are ***between*** all numbers used by the comment’s ancestors.

# What Does This Look Like?



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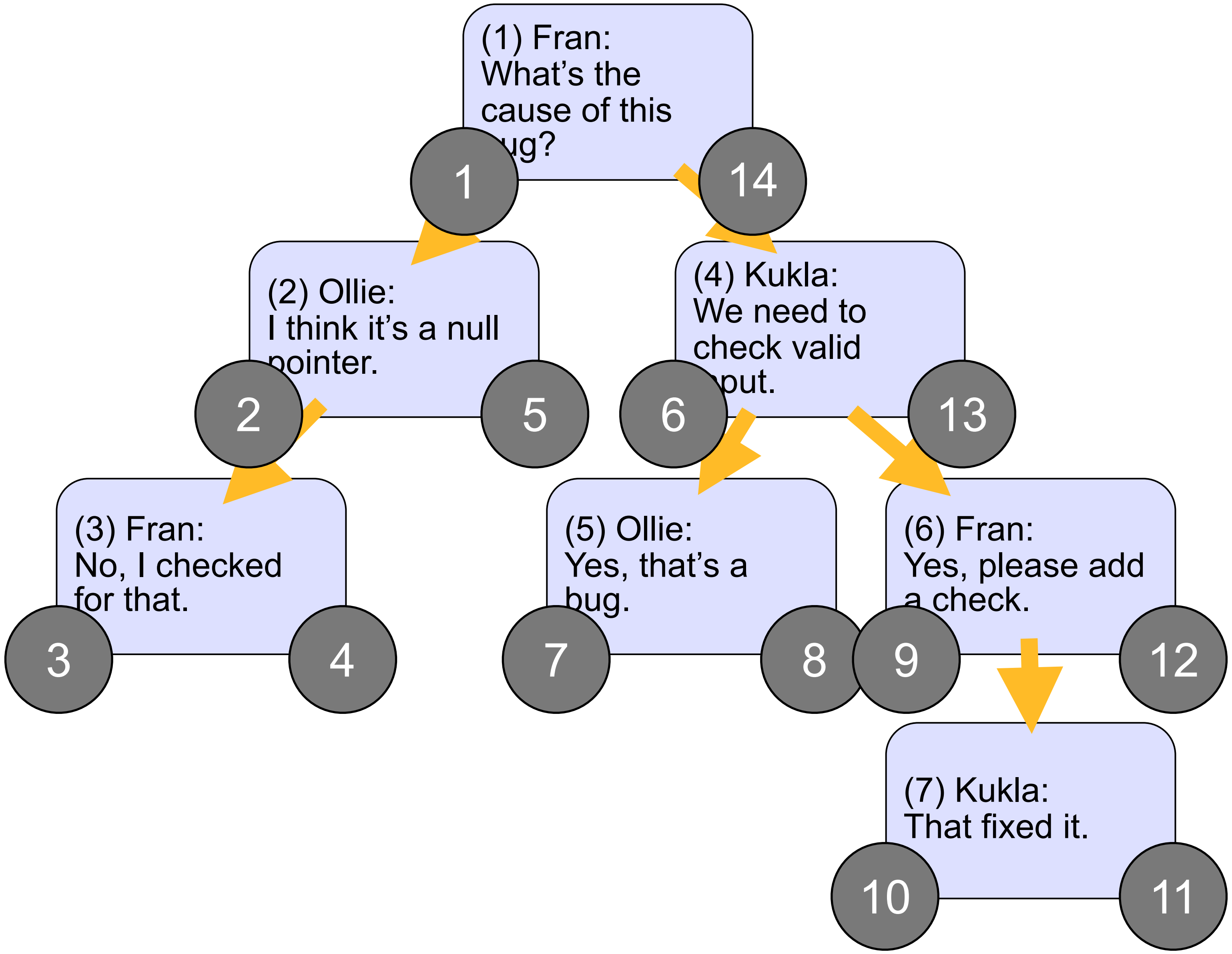

(1) Fran:
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cause of this
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(2) Ollie:
I think it's a null
pointer.

(3) Fran:
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(4) Kukla:
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check valid
input.

(5) Ollie:
Yes, that's a
bug.

(6) Fran:
Yes, please add
a check.

(7) Kukla:
That fixed it.

# What Does This Look Like?

| comment_id | nsleft | nsright | author | comment |
|---|---|---|---|---|
| 1 | 1 | 14 | Fran | What’s the cause of this bug? |
| 2 | 2 | 5 | Ollie | I think it’s a null pointer. |
| 3 | 3 | 4 | Fran | No, I checked for that. |
| 4 | 6 | 13 | Kukla | We need to check valid input. |
| 5 | 7 | 8 | Ollie | Yes, that’s a bug. |
| 6 | 9 | 12 | Fran | Yes, please add a check |
| 7 | 10 | 11 | Kukla | That fixed it. |

# What Does This Look Like?

| comment_id | nsleft | nsright | author | comment |
|---|---|---|---|---|
| 1 | 1 | 14 | Fran | What's the cause of this bug? |
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| 6 | 9 | 12 | Fran | Yes, please add a check |
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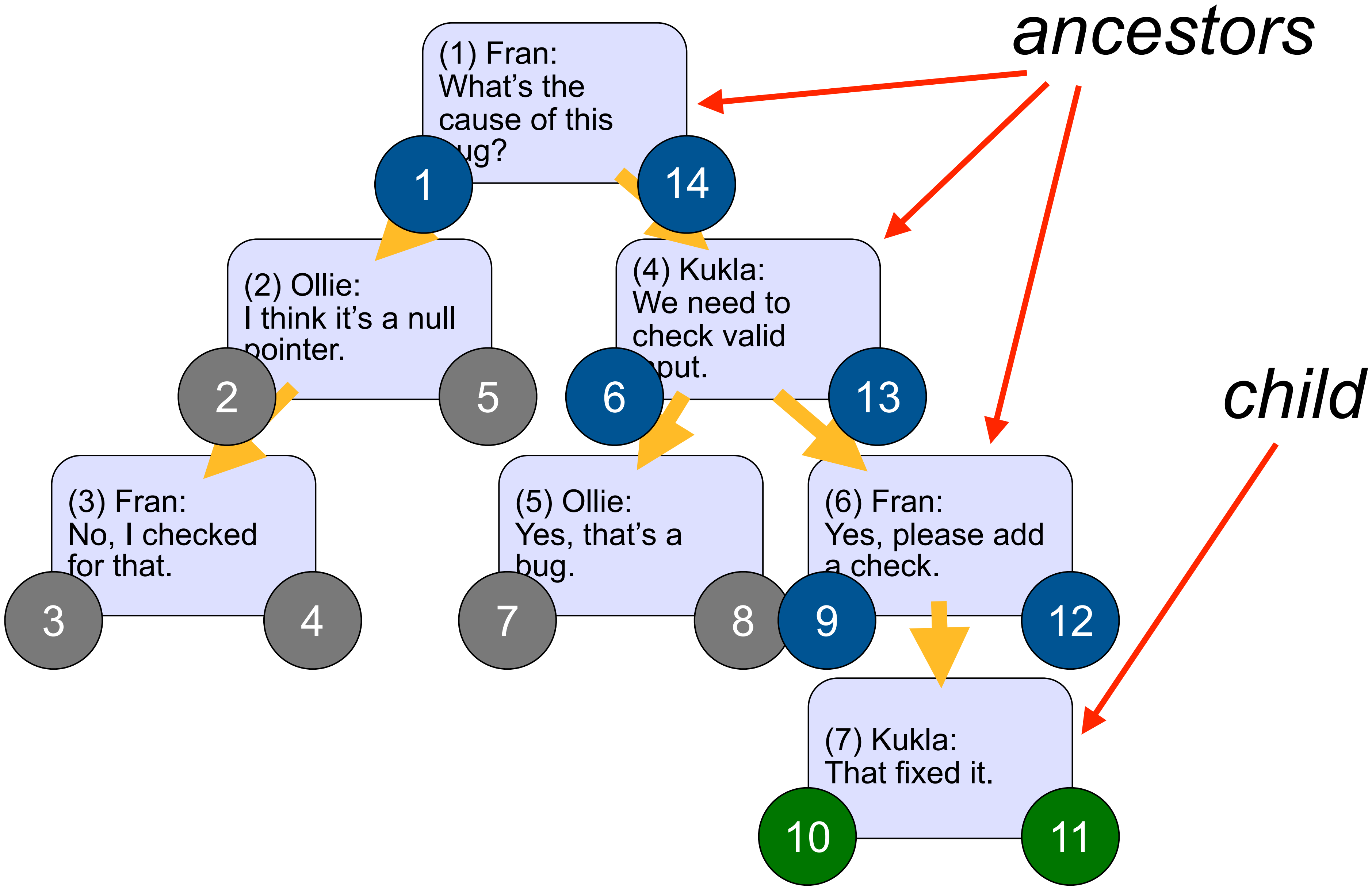
*these are not foreign keys*

# Query Ancestors of #7

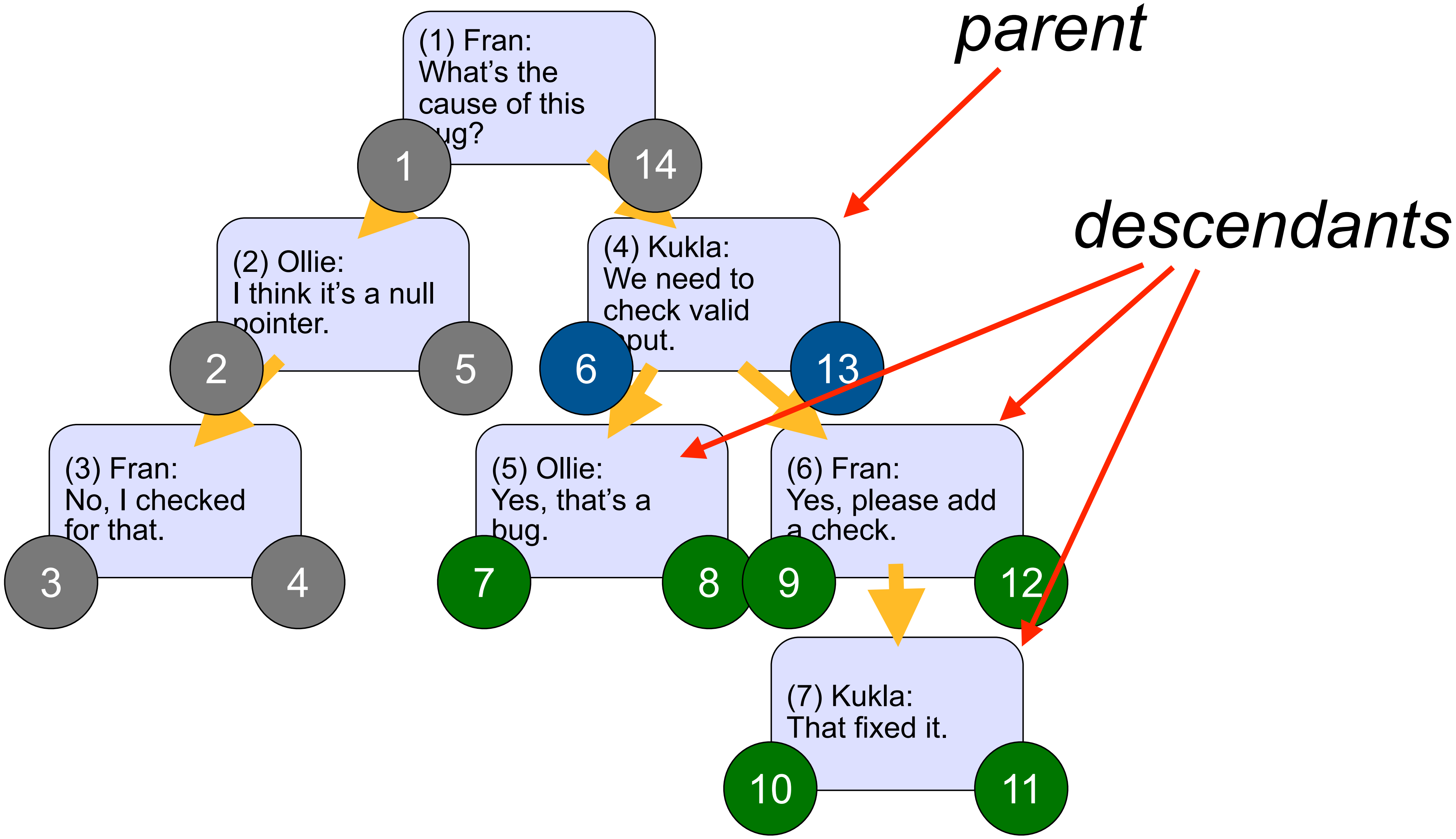


ancestors
child
(1) Fran: What's the cause of this bug?
1
14
(2) Ollie: I think it's a null pointer.
2
5
(3) Fran: No, I checked for that.
3
4
(4) Kukla: We need to check valid input.
6
13
(5) Ollie: Yes, that's a bug.
7
8
(6) Fran: Yes, please add a check.
9
12
(7) Kukla: That fixed it.
10
11

# Query Ancestors of #7

```
SELECT * FROM Comments child
  JOIN Comments ancestor ON child.nsleft
      BETWEEN ancestor.nsleft AND ancestor.nsright
  WHERE child.comment_id = 7;
```

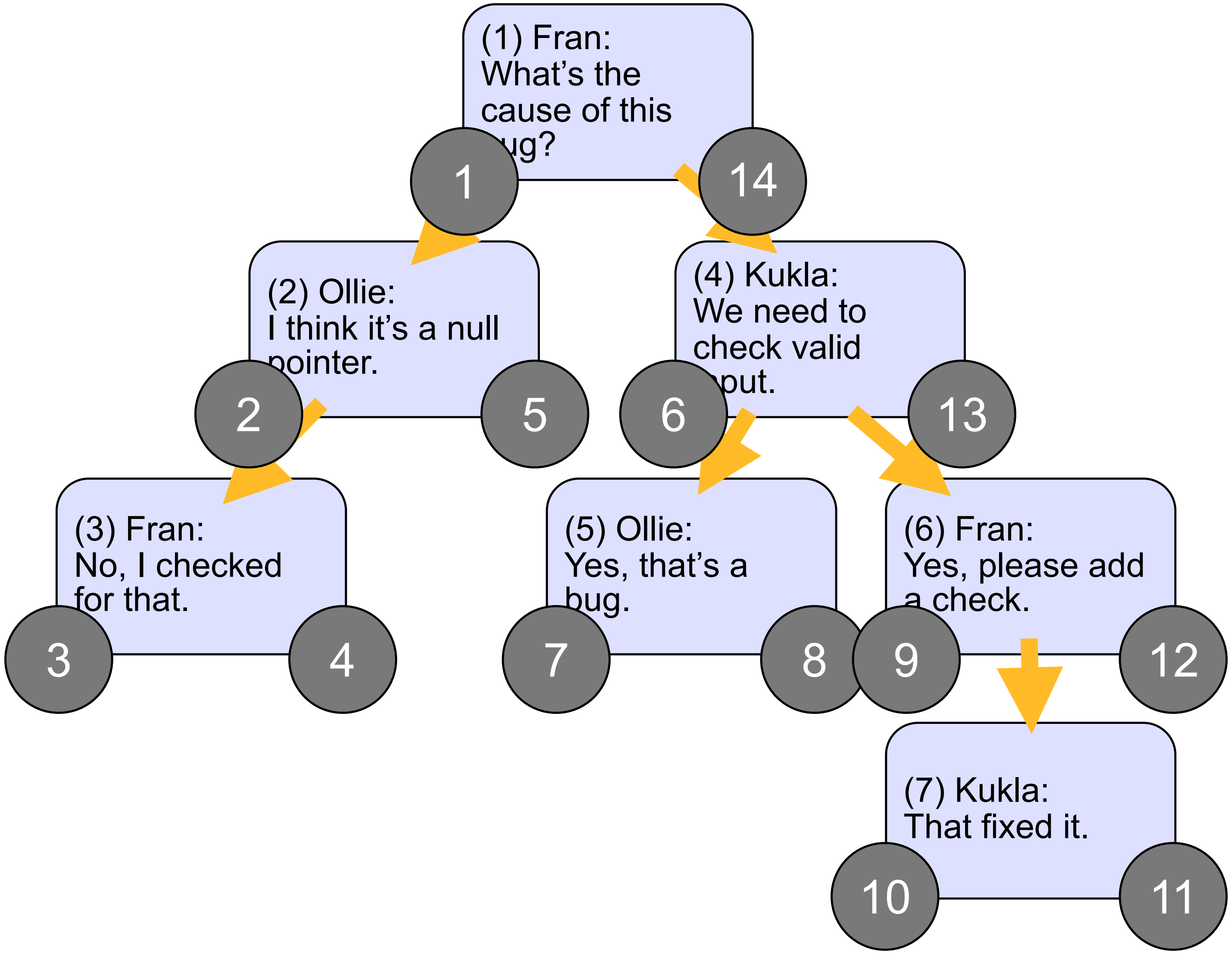
# Query Subtree Under #4



# Query Subtree Under #4

```
SELECT * FROM Comments parent
  JOIN Comments descendant ON descendant.nsleft
     BETWEEN parent.nsleft AND parent.nsright
  WHERE parent.comment_id = 4;
```

# Insert New Child of #5



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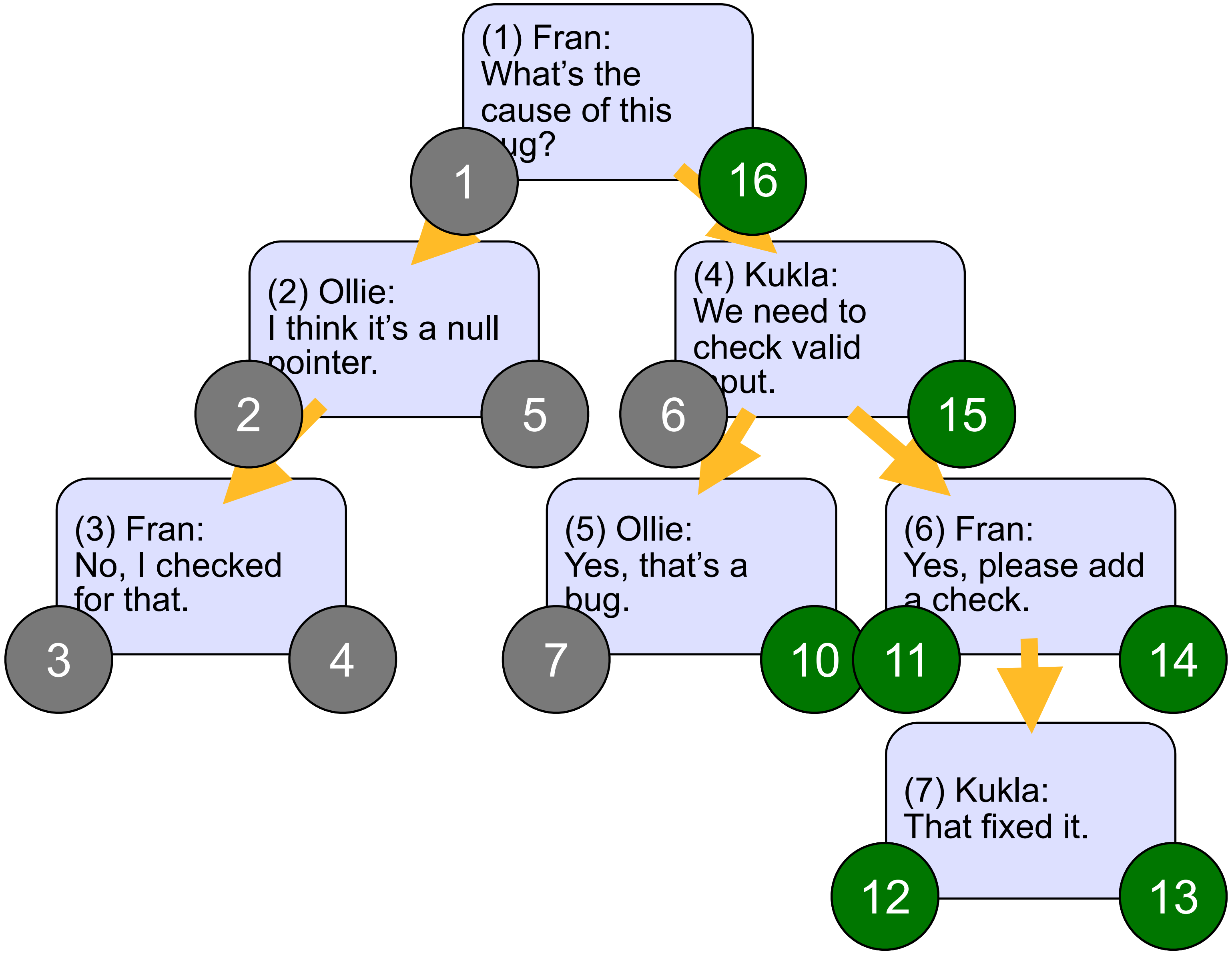
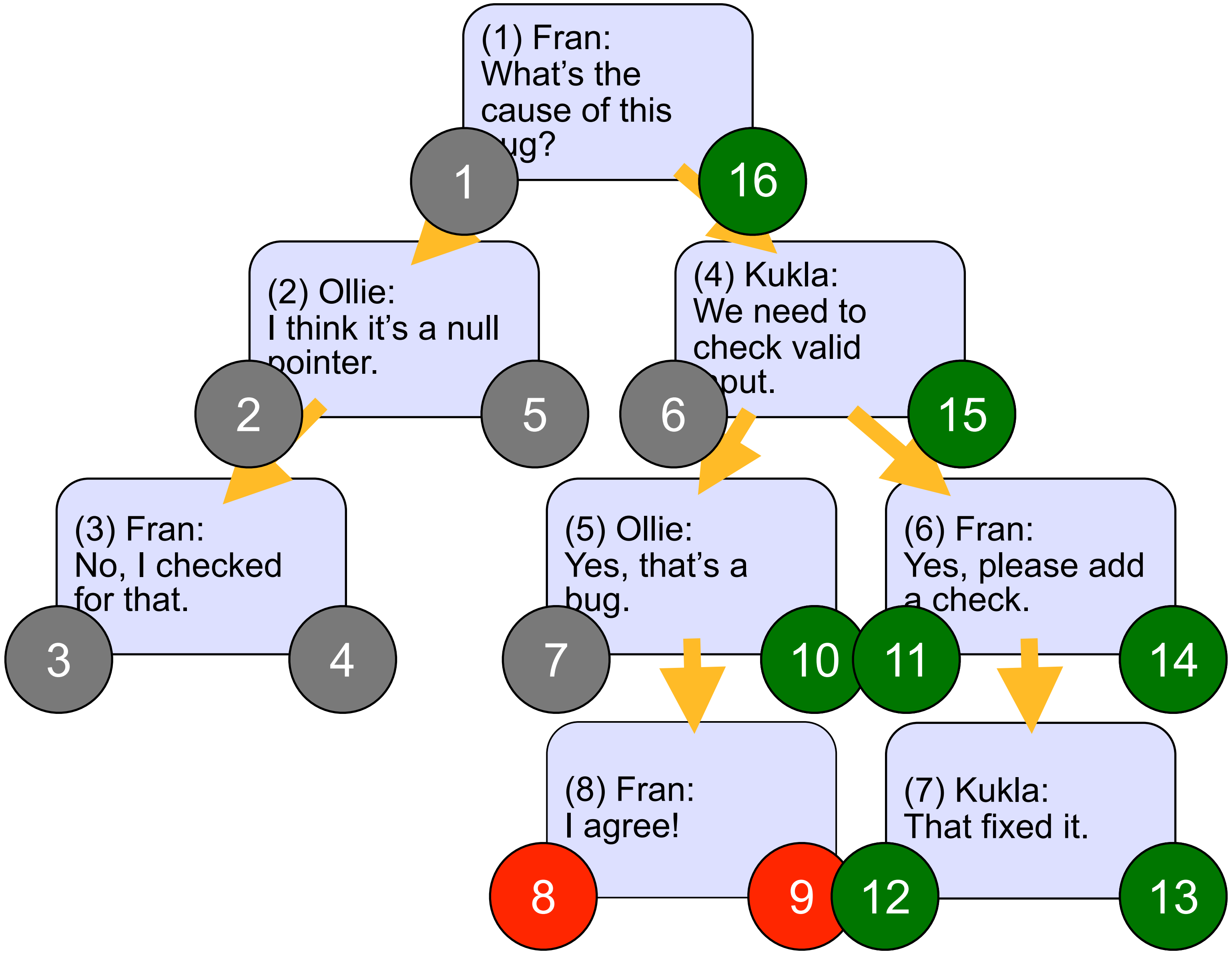


# Insert New Child of #5



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(6) Fran:
Yes, please add a check.

(8) Fran:
I agree!

(7) Kukla:
That fixed it.

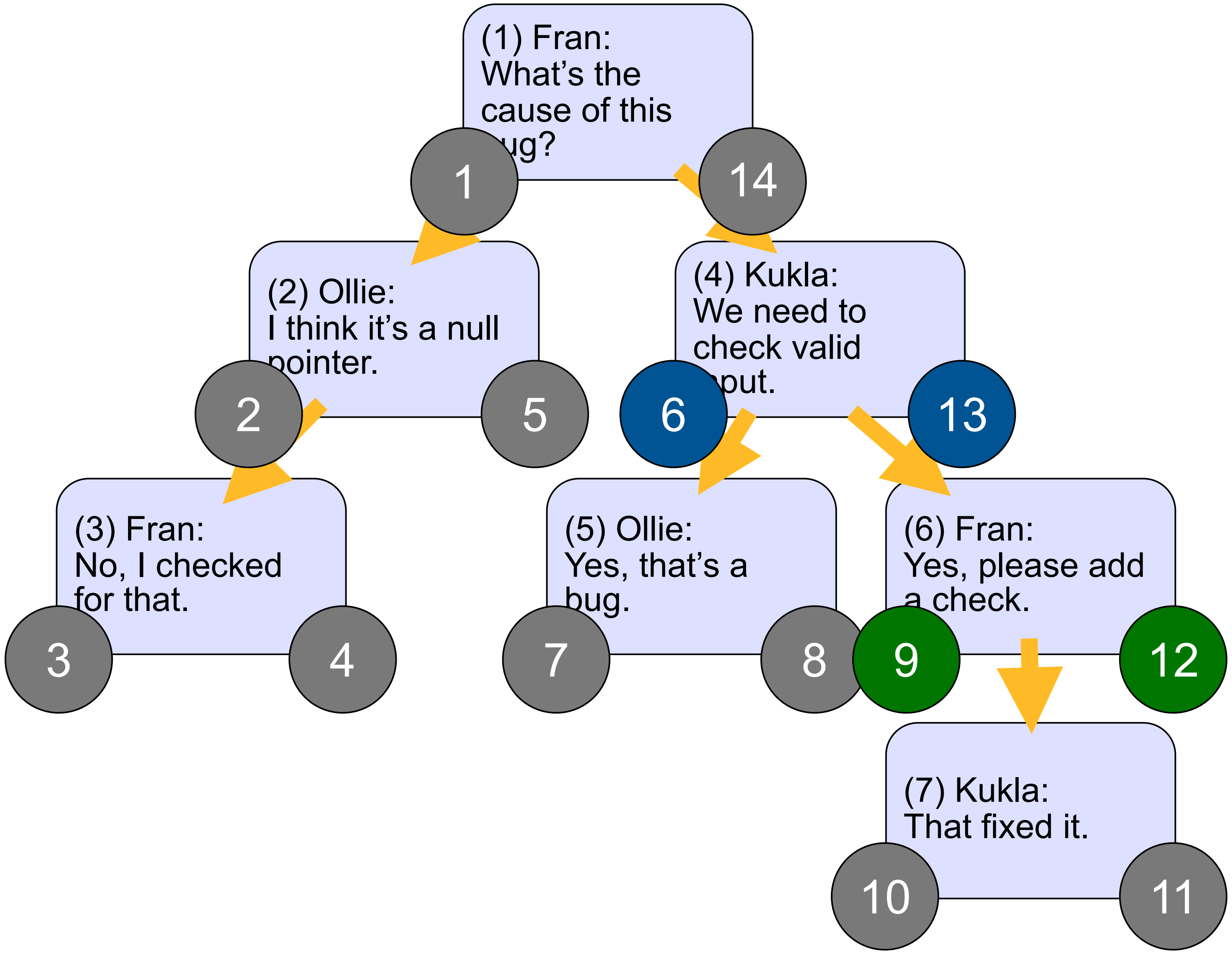
# Insert New Child of #5

```
UPDATE Comments
  SET     nsleft = CASE WHEN nsleft >= 8 THEN nsleft+2
            ELSE nsleft END,
            nsright = nsright+2
  WHERE nsright >= 7;

INSERT INTO Comments (nsleft, nsright, author, comment)
     VALUES (8, 9, 'Fran', 'I agree!');
```

- Recalculate ***left*** values for all nodes to the right of the new child. Recalculate ***right*** values for all nodes above and to the right.

# Query Immediate Parent of #6



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# Query Immediate Parent of #6

- Parent of #6 is an ancestor who has no descendant who is also an ancestor of #6.

```
SELECT parent.* FROM Comments AS c
    JOIN Comments AS parent
      ON (c.nsleft BETWEEN parent.nsleft AND parent.nsright)
    LEFT OUTER JOIN Comments AS in_between
      ON (c.nsleft BETWEEN in_between.nsleft AND in_between.nsright
        AND in_between.nsleft BETWEEN parent.nsleft AND parent.nsright)
    WHERE c.comment_id = 6 AND in_between.comment_id IS NULL;
```

# Query Immediate Parent of #6

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```
SELECT parent.* FROM Comments AS c
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      ON (c.nsleft BETWEEN parent.nsleft AND parent.nsright)
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        AND in_between.nsleft BETWEEN parent.nsleft AND parent.nsright)
    WHERE c.comment_id = 6 AND in_between.comment_id IS NULL;
```

*querying immediate child*
*is a similar problem*

# Closure Table

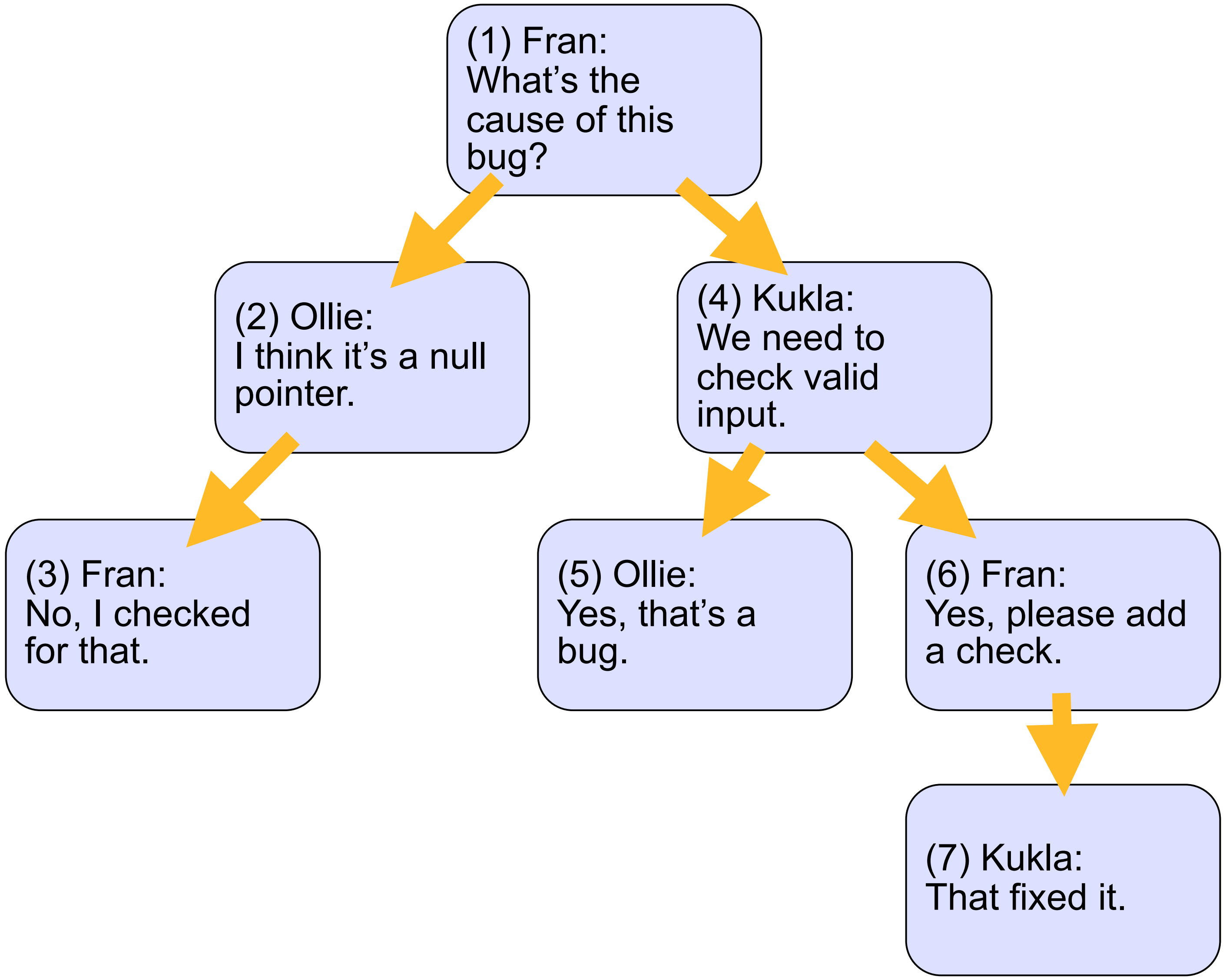
# Closure Table

```
CREATE TABLE TreePaths (
        ancestor        INT NOT NULL,
        descendant      INT NOT NULL,
        PRIMARY KEY (ancestor, descendant),
        FOREIGN KEY(ancestor)
            REFERENCES Comments(comment_id),
        FOREIGN KEY(descendant)
            REFERENCES Comments(comment_id)
  );
```

# Closure Table

- Many-to-many table
- Stores every path from each node to each of its descendants
- A node even connects to itself

# Closure Table illustration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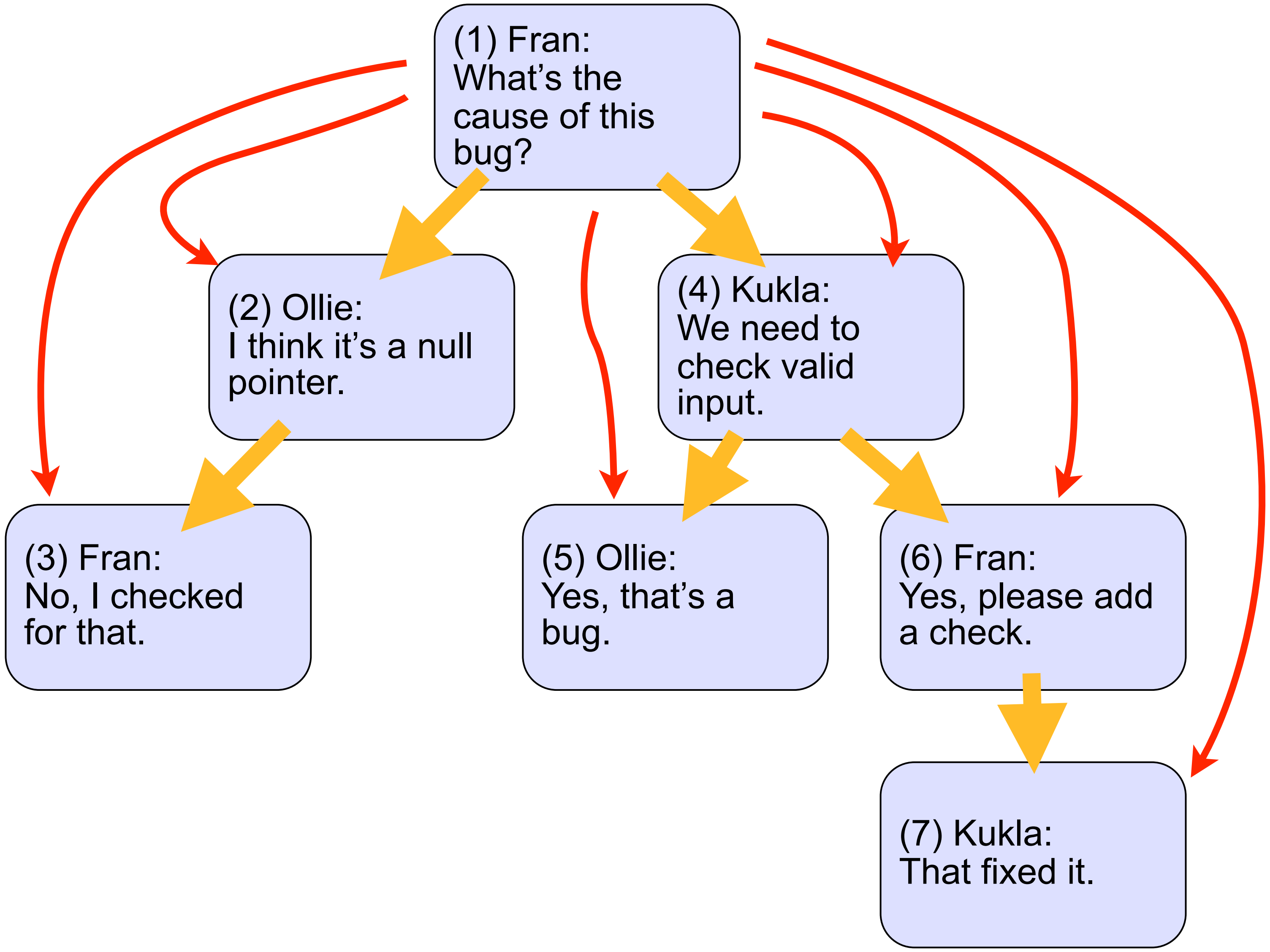

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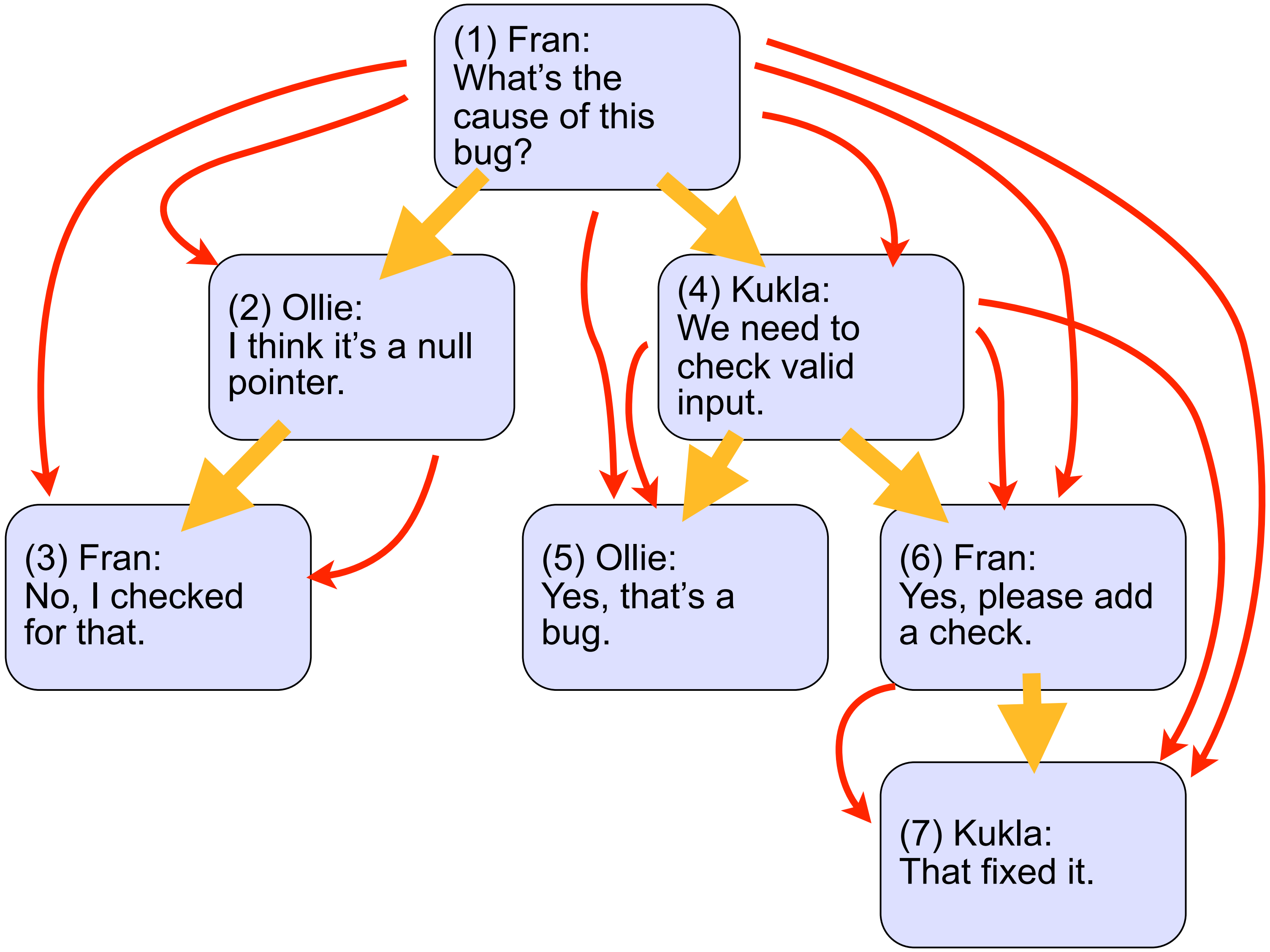

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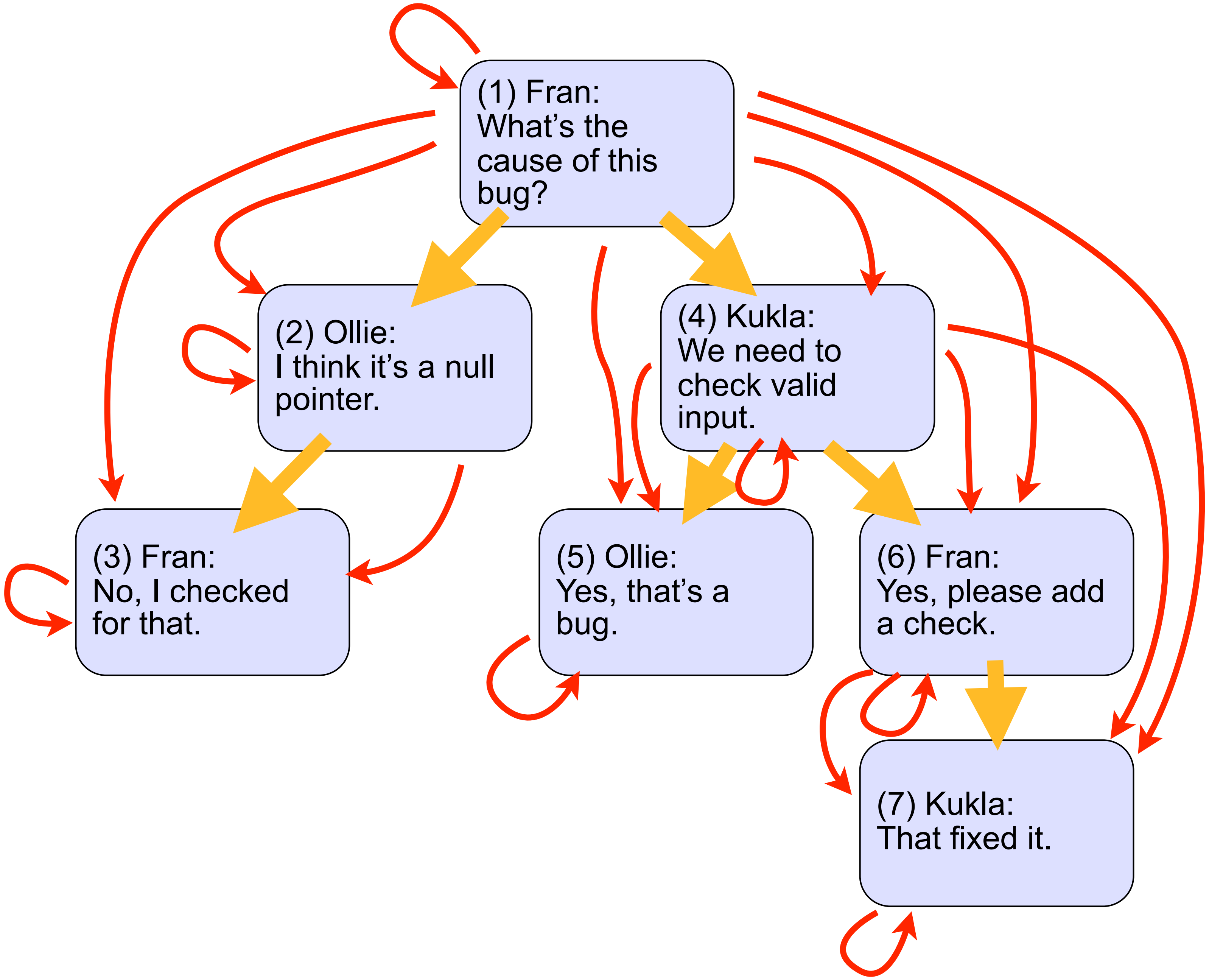

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|---|---|---|
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| ancestor | descendant |
|---|---|
| 1 | 1 |
| 1 | 2 |
| 1 | 3 |
| 1 | 4 |
| 1 | 5 |
| 1 | 6 |
| 1 | 7 |
| 2 | 2 |
| 2 | 3 |
| 3 | 3 |
| 4 | 4 |
| 4 | 5 |
| 4 | 6 |
| 4 | 7 |
| 5 | 5 |
| 6 | 6 |
| 6 | 7 |
| 7 | 7 |

*requires $O(n^2)$ rows* →

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|---|---|---|
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| 1 | 6 |
| 1 | 7 |
| 2 | 2 |
| 2 | 3 |
| 3 | 3 |
| 4 | 4 |
| 4 | 5 |
| 4 | 6 |
| 4 | 7 |
| 5 | 5 |
| 6 | 6 |
| 6 | 7 |
| 7 | 7 |

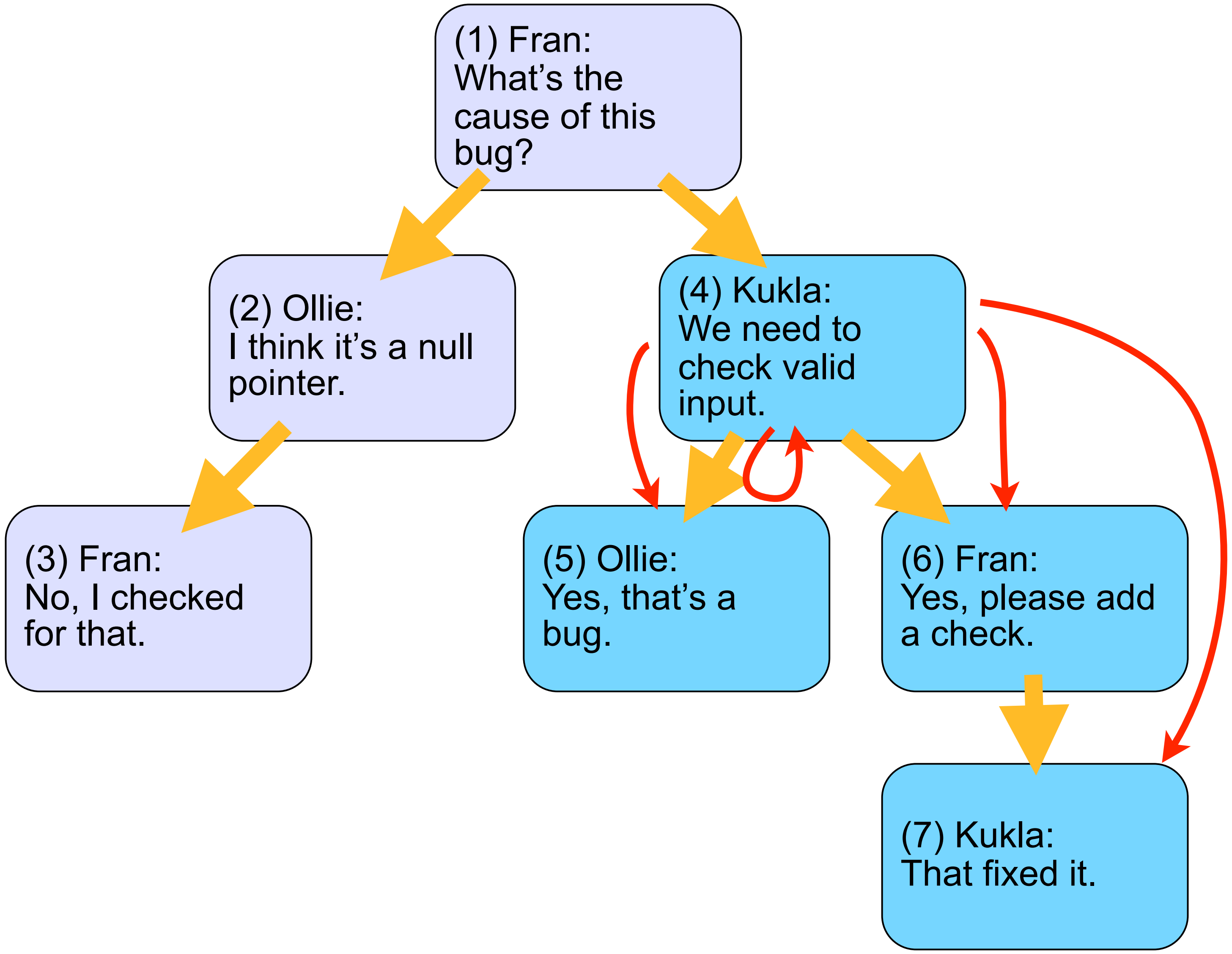
*requires O(n²) rows* →

*(but far fewer in practice)*

# Query Descendants of #4

```
SELECT c.* FROM Comments c
  JOIN TreePaths t
    ON (c.comment_id = t.descendant)
  WHERE t.ancestor = 4;
```

# Paths Starting from #4



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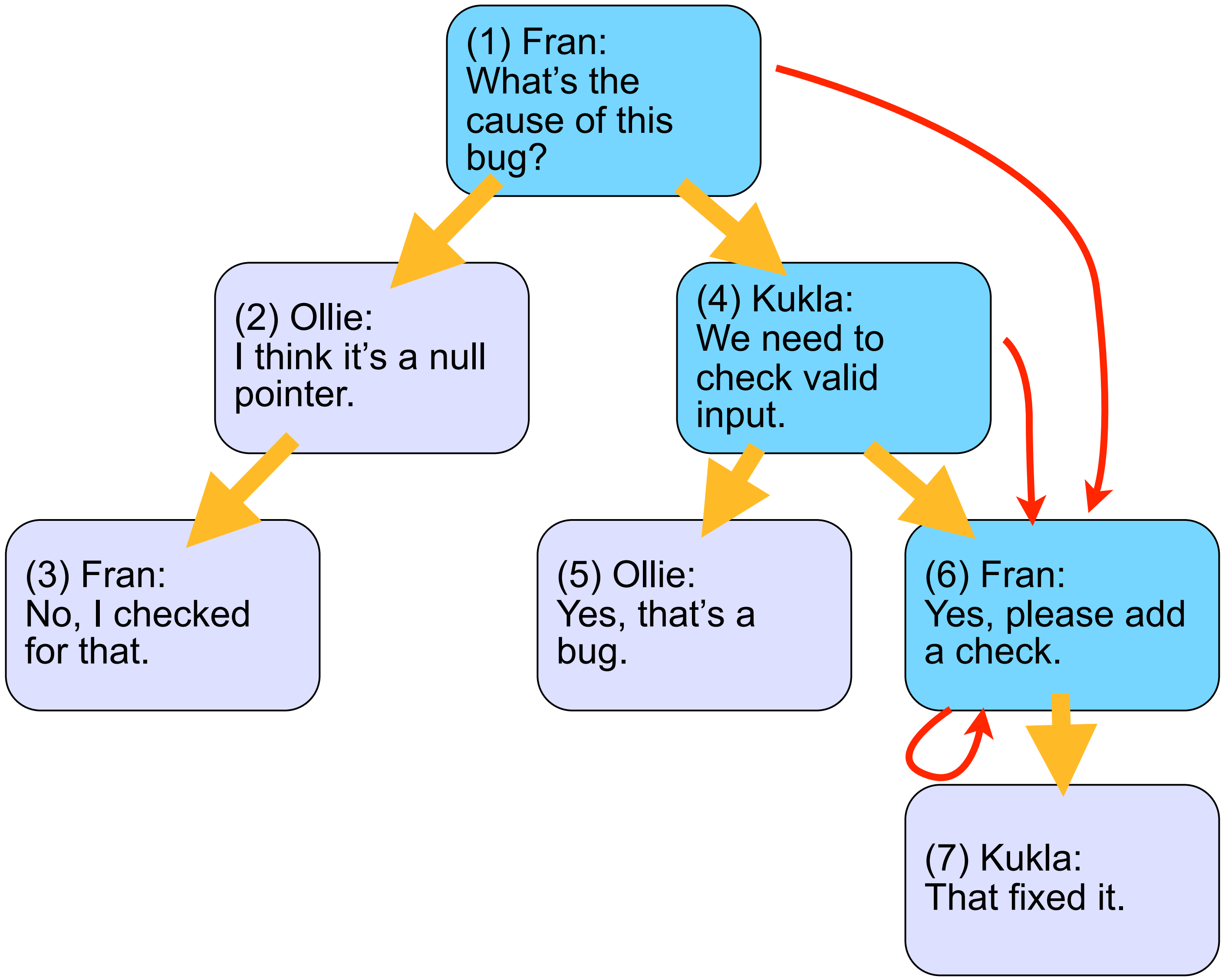
That fixed it.

# Query Ancestors of #6

```
SELECT c.* FROM Comments c
  JOIN TreePaths t
   ON (c.comment_id = t.ancestor)
  WHERE t.descendant = 6;
```

# Paths Terminating at #6



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(5) Ollie:
Yes, that's a bug.

(6) Fran:
Yes, please add a check.

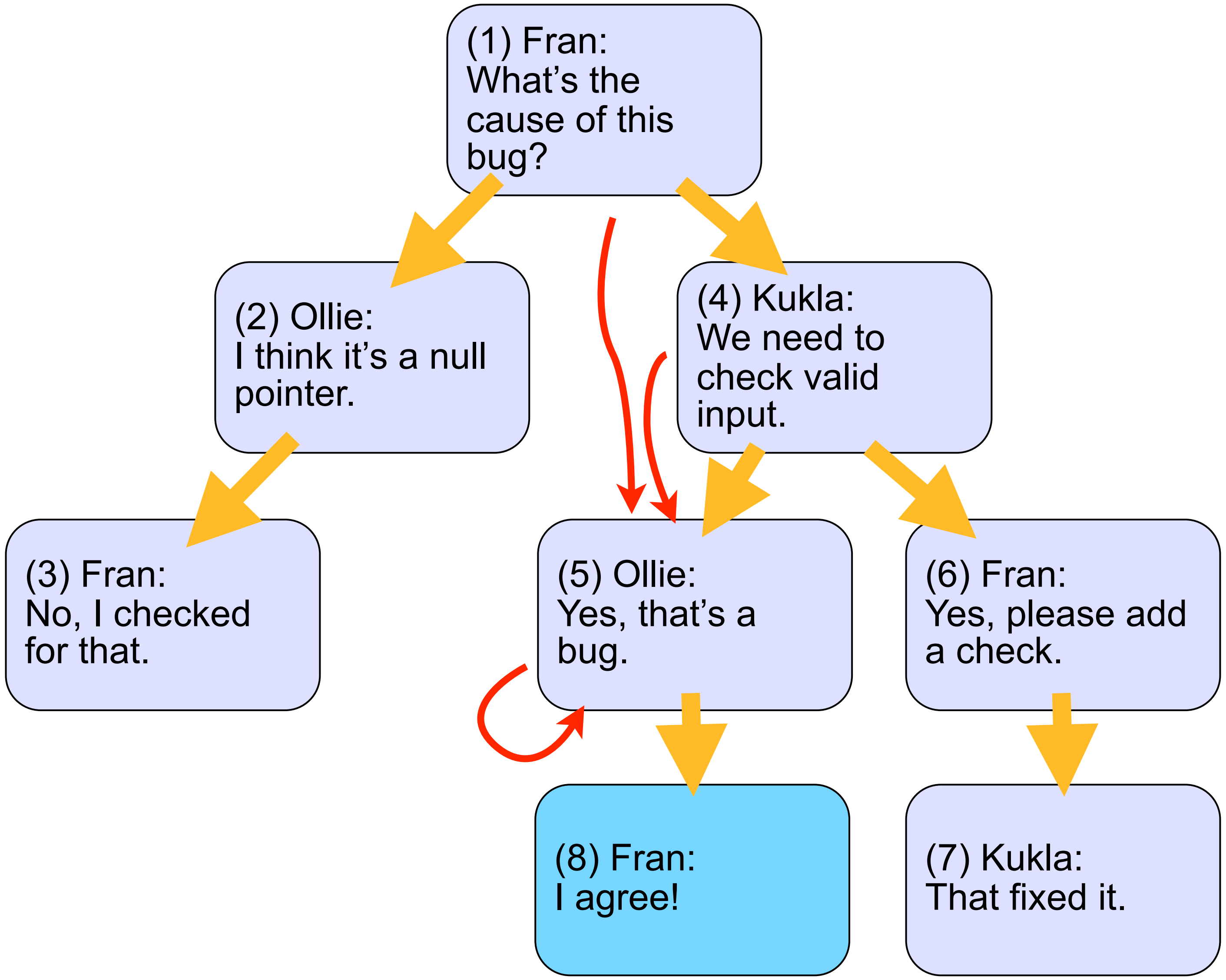
(7) Kukla:
That fixed it.

# Insert New Child of #5

```
INSERT INTO Comments
   VALUES (8, ‘Fran’, ‘I agree!’);

INSERT INTO TreePaths (ancestor, descendant)
   SELECT ancestor, 8 FROM TreePaths
   WHERE descendant = 5
   UNION ALL SELECT 8, 8;
```

# Copy Paths from Parent



(1) Fran:
What's the cause of this bug?

(2) Ollie:
I think it's a null pointer.

(3) Fran:
No, I checked for that.

(4) Kukla:
We need to check valid input.

(5) Ollie:
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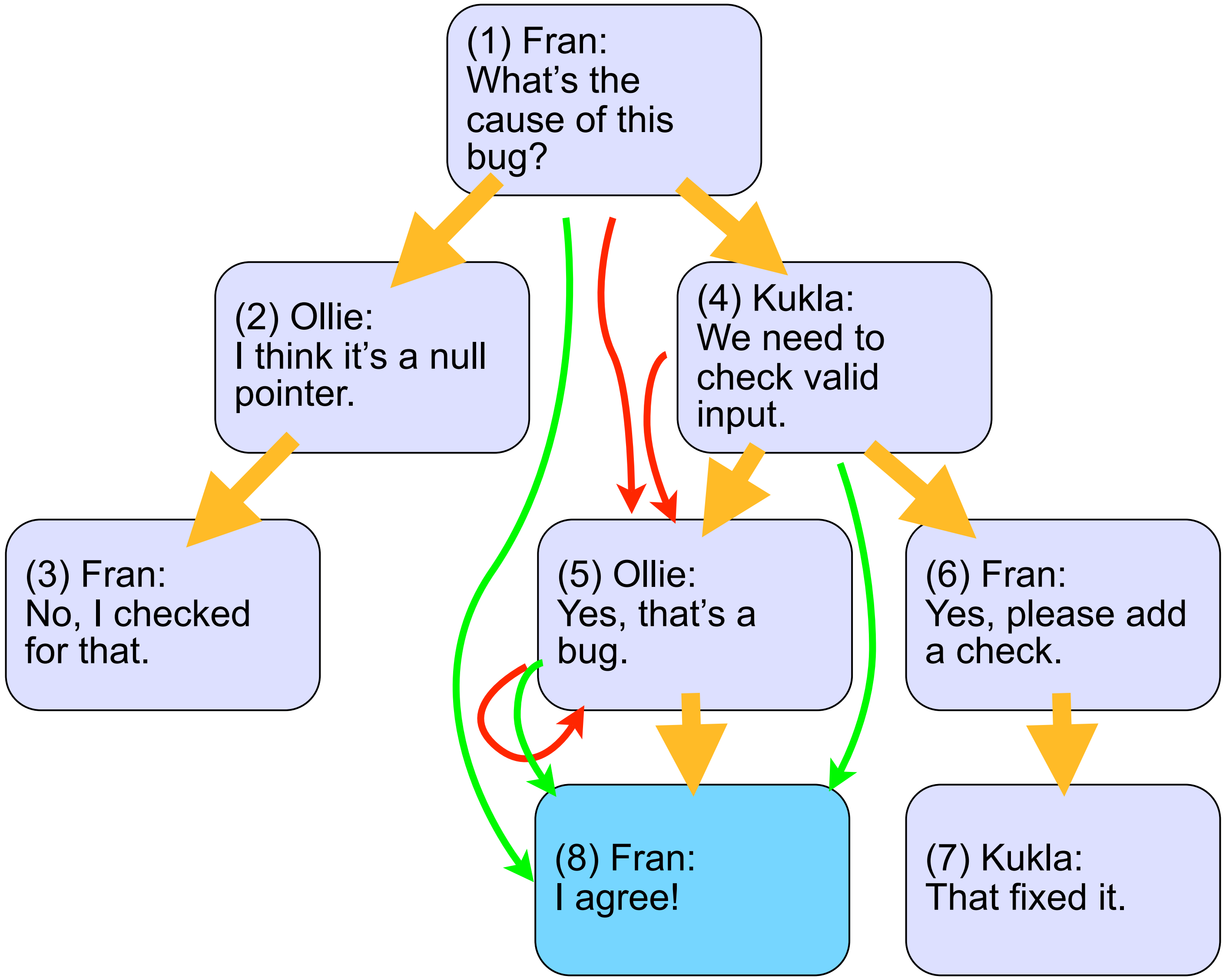
(6) Fran:
Yes, please add a check.

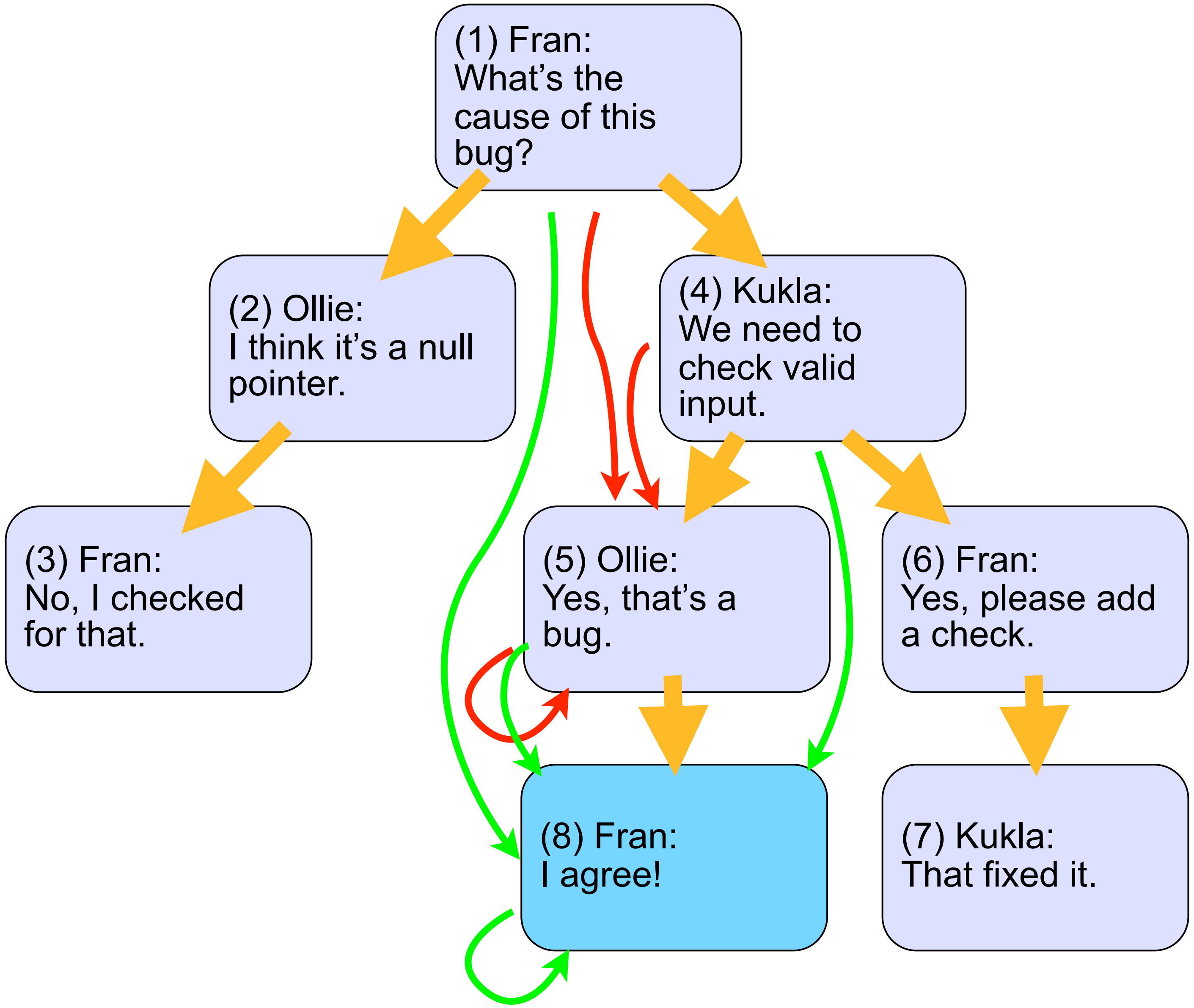
(7) Kukla:
That fixed it.

(8) Fran:
I agree!

# Copy Paths from Parent



# Copy Paths from Parent



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(6) Fran:
Yes, please add a check.

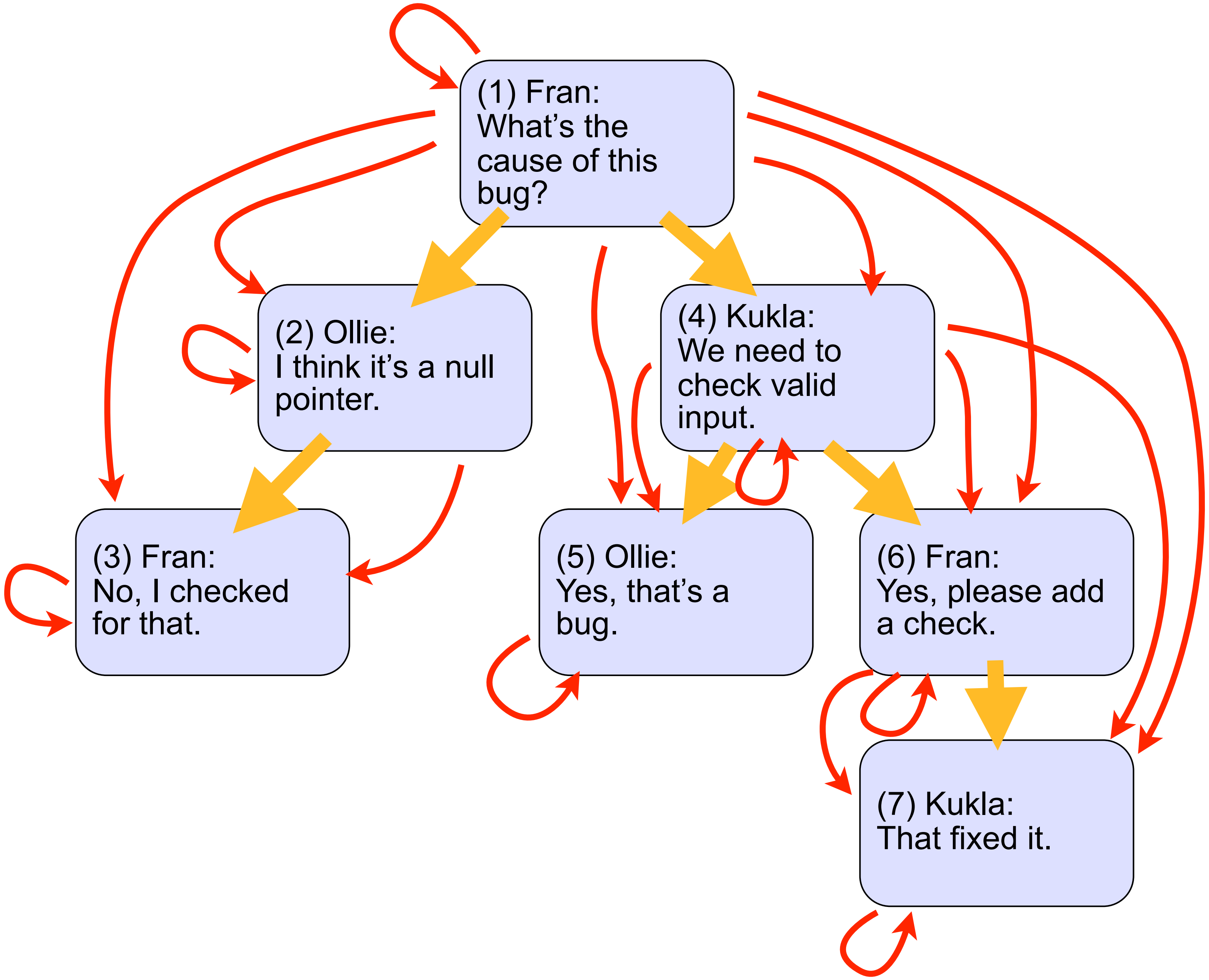
(7) Kukla:
That fixed it.

(8) Fran:
I agree!

# Delete Child #7

```
DELETE FROM TreePaths
    WHERE descendant = 7;
```

# Delete Paths Terminating at #7



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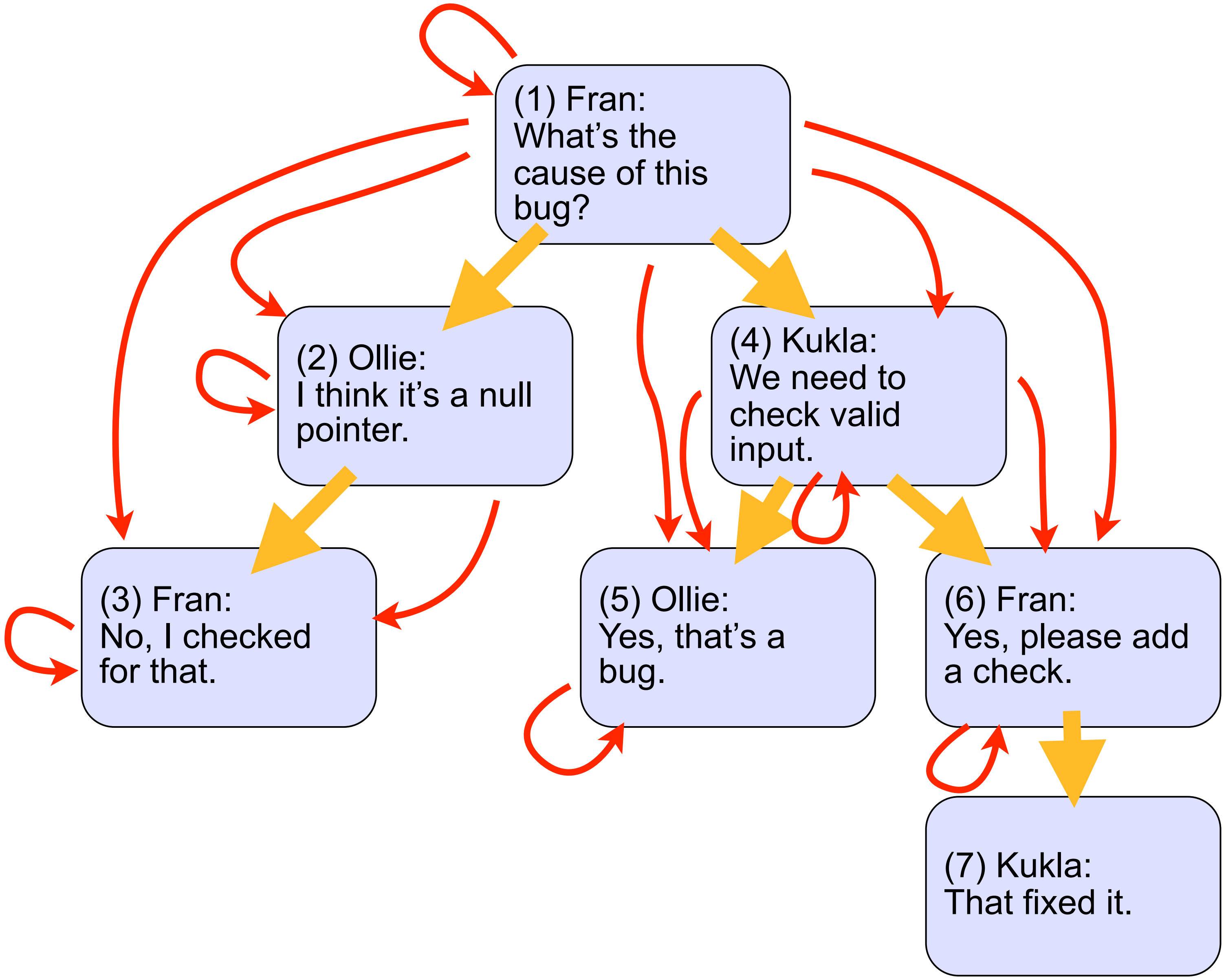

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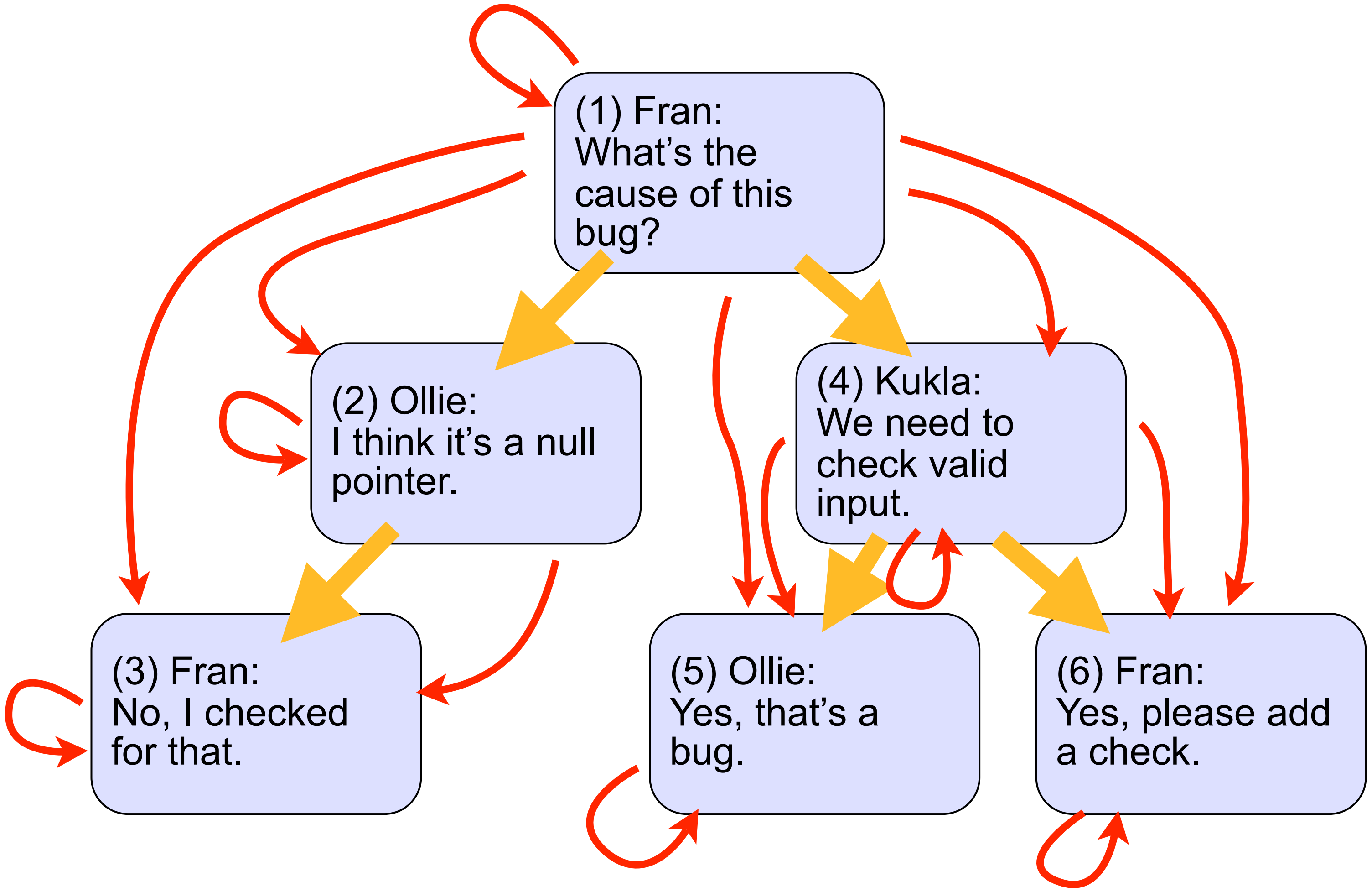

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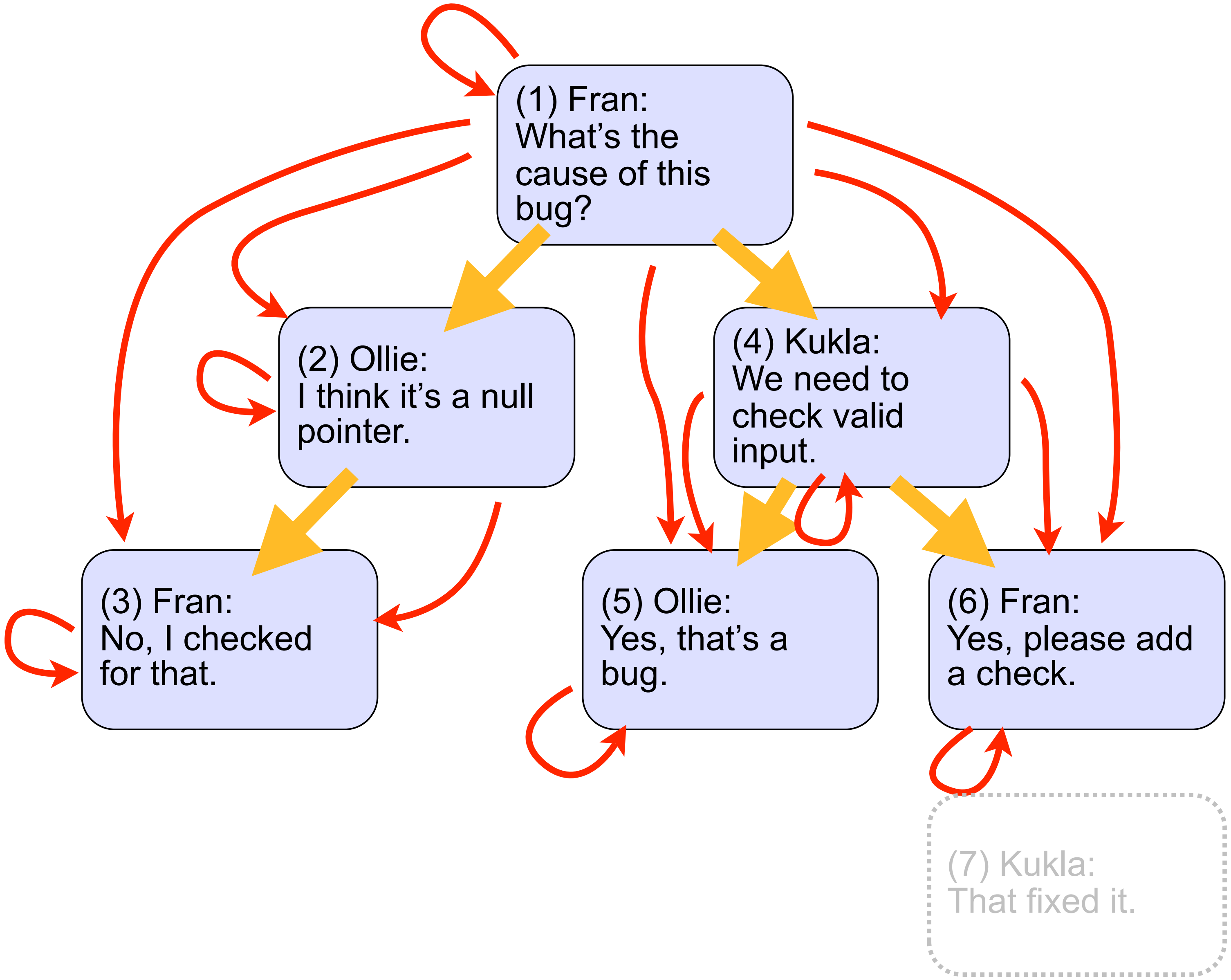

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(5) Ollie:
Yes, that's a bug.

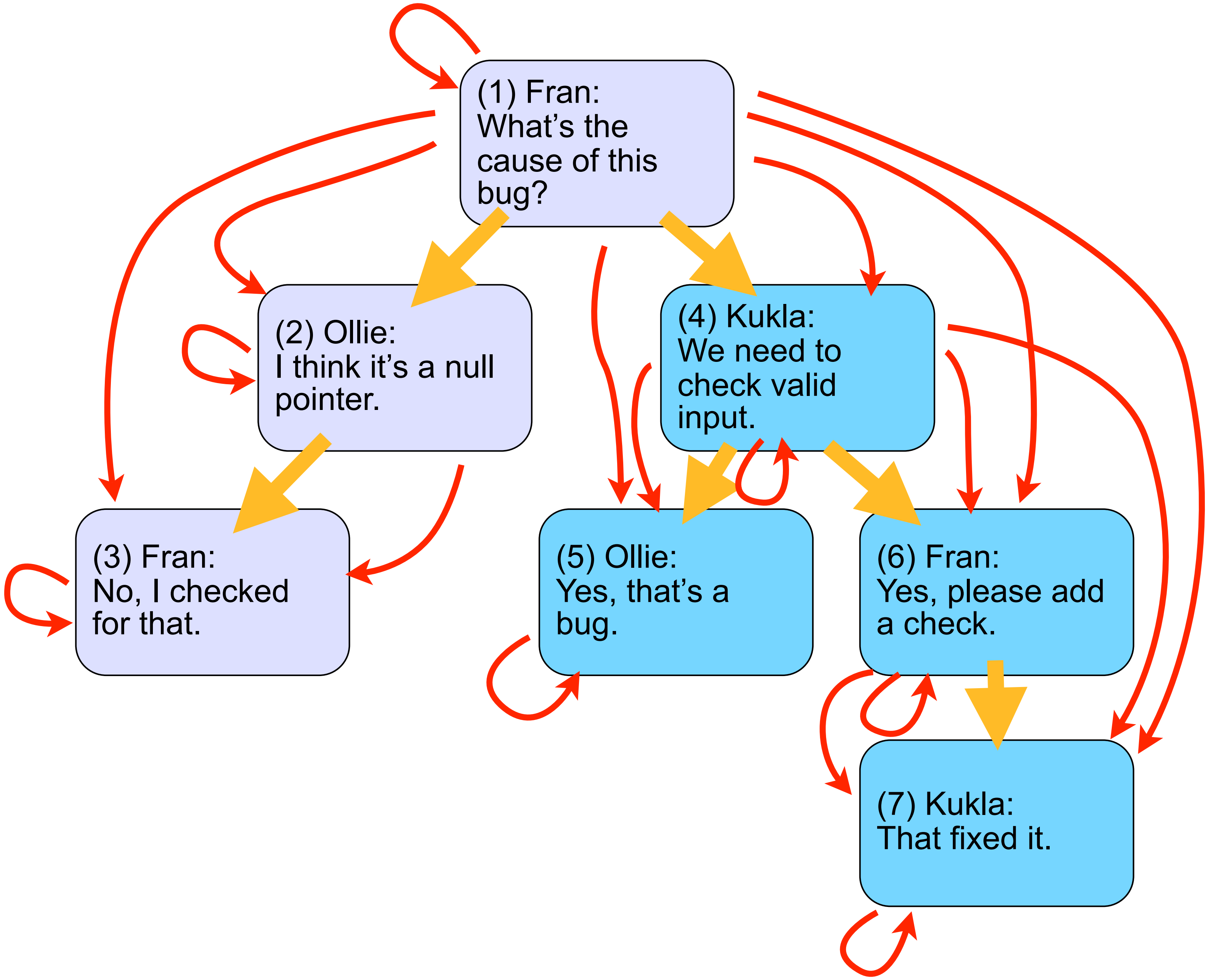
(6) Fran:
Yes, please add a check.

(7) Kukla:
That fixed it.

# Delete Subtree Under #4

```
DELETE FROM TreePaths
    WHERE descendant IN
        (SELECT descendant FROM TreePaths
         WHERE ancestor = 4);
```

# Delete Any Paths Under #4



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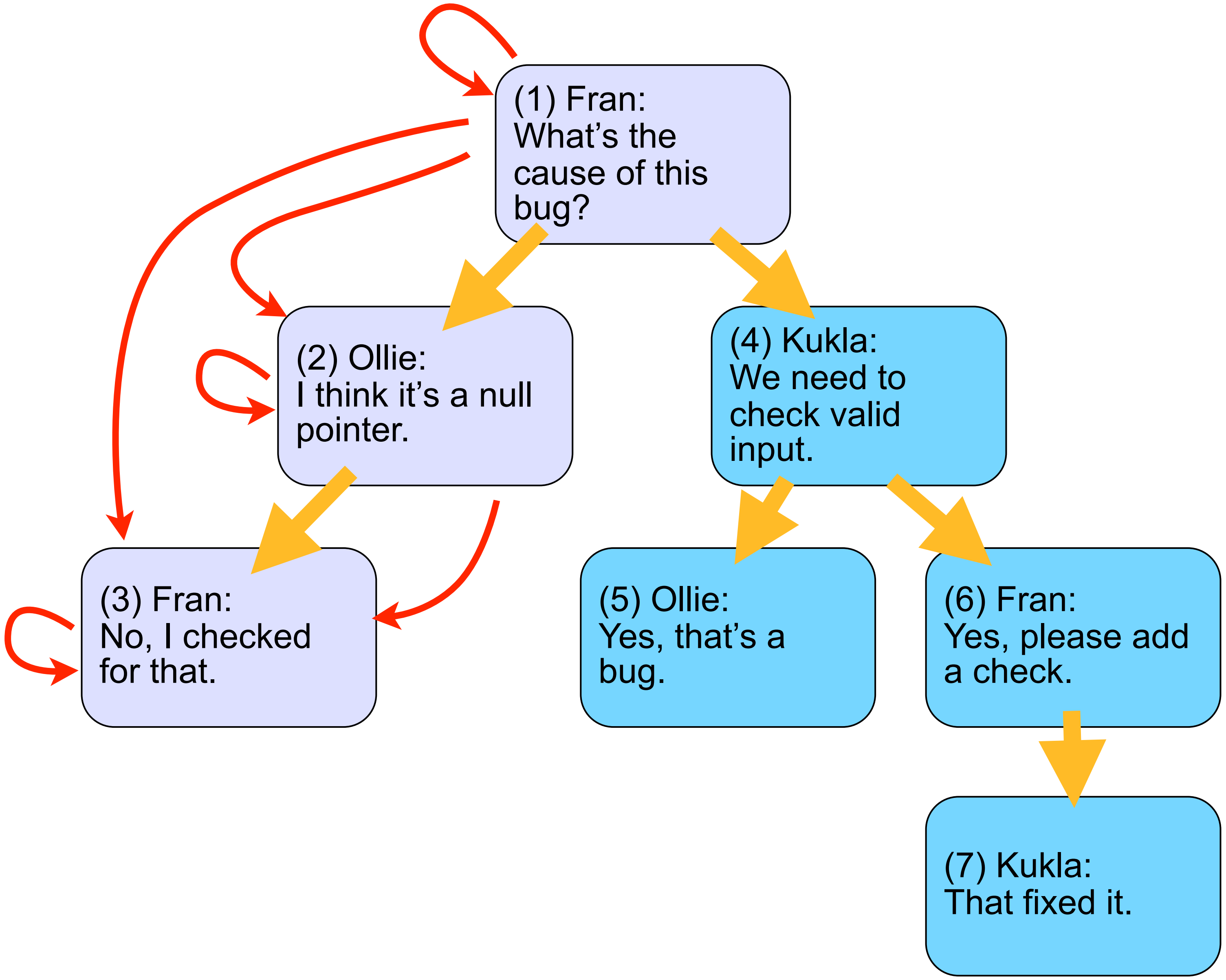
# Delete Any Paths Under #4



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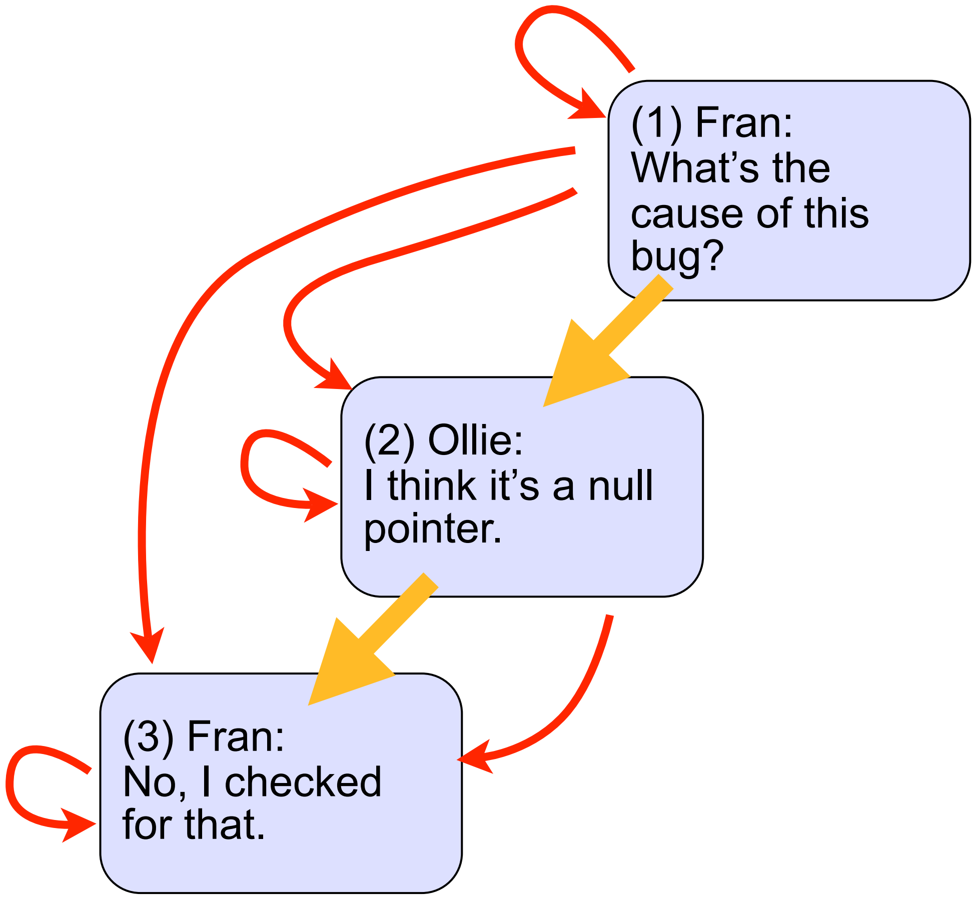
# Delete Any Paths Under #4



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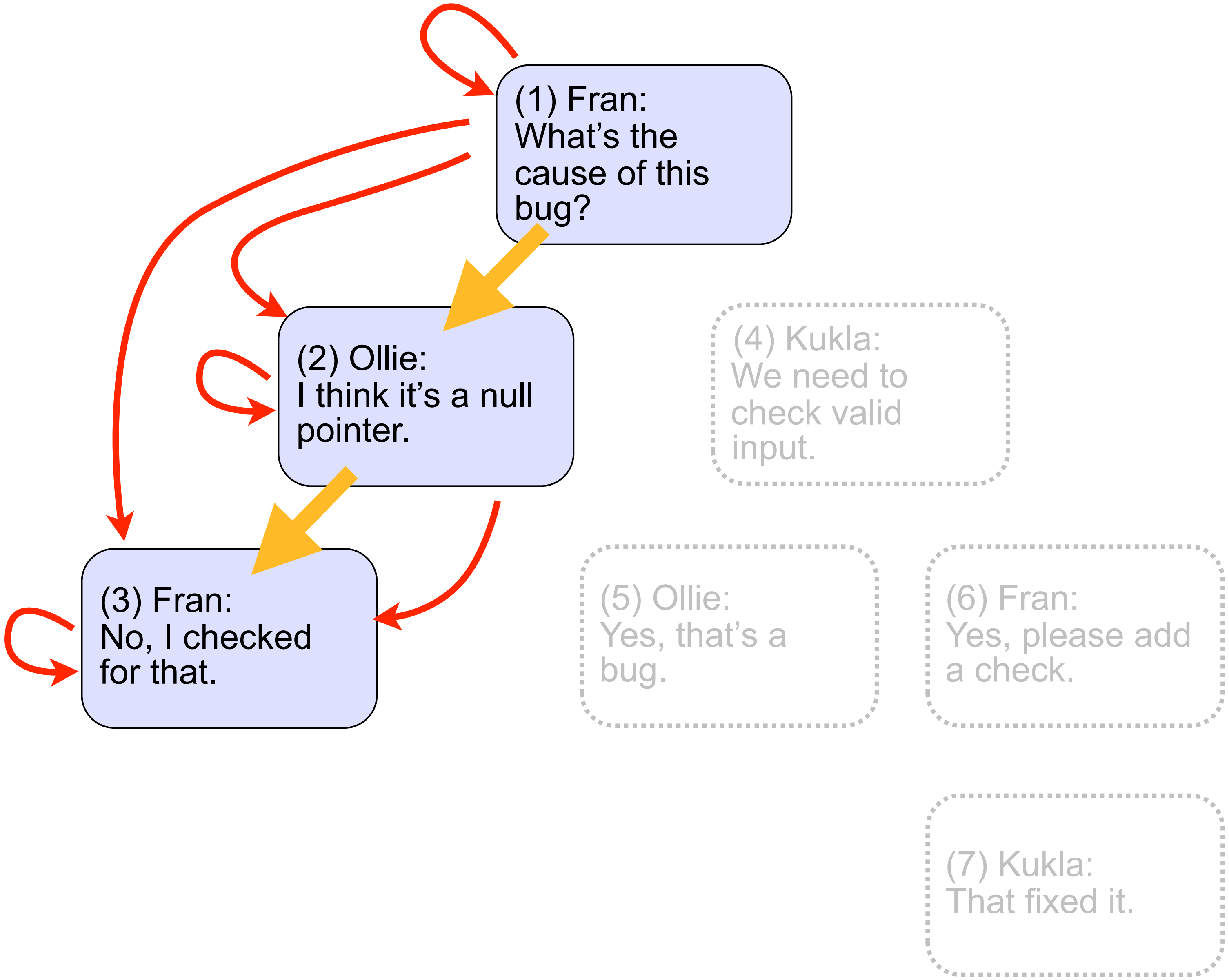
# Delete Any Paths Under #4



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That fixed it.

# Path Length

- Add a *length* column
- MAX(length) is depth of tree
- Makes it easier to query immediate parent or child:

```
SELECT c.*
  FROM Comments c
  JOIN TreePaths t
    ON (c.comment_id = t.descendant)
  WHERE t.ancestor = 4
    AND t.length = 1;
```

| ancestor | descendant | length |
|---|---|---|
| 1 | 1 | 0 |
| 1 | 2 | 1 |
| 1 | 3 | 2 |
| 1 | 4 | 1 |
| 1 | 5 | 2 |
| 1 | 6 | 2 |
| 1 | 7 | 3 |
| 2 | 2 | 0 |
| 2 | 3 | 1 |
| 3 | 3 | 0 |
| 4 | 4 | 0 |
| 4 | 5 | 1 |
| 4 | 6 | 1 |
| 4 | 7 | 2 |
| 5 | 5 | 0 |
| 6 | 6 | 0 |
| 6 | 7 | 1 |
| 7 | 7 | 0 |

# Path Length

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```
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  JOIN TreePaths t
    ON (c.comment_id = t.descendant)
  WHERE t.ancestor = 4
    AND t.length = 1;
```

| ancestor | descendant | length |
|---|---|---|
| 1 | 1 | 0 |
| 1 | 2 | 1 |
| 1 | 3 | 2 |
| 1 | 4 | 1 |
| 1 | 5 | 2 |
| 1 | 6 | 2 |
| 1 | 7 | 3 |
| 2 | 2 | 0 |
| 2 | 3 | 1 |
| 3 | 3 | 0 |
| 4 | 4 | 0 |
| 4 | 5 | 1 |
| 4 | 6 | 1 |
| 4 | 7 | 2 |
| 5 | 5 | 0 |
| 6 | 6 | 0 |
| 6 | 7 | 1 |
| 7 | 7 | 0 |

# Choosing the Right Design

| Design | Tables | Query Child | Query Subtree | Delete Node | Insert Node | Move Subtree | Referential Integrity |
|---|---|---|---|---|---|---|---|
| Adjacency List | 1 | Easy | Hard | Easy | Easy | Easy | Yes |
| Path Enumeration | 1 | Hard | Easy | Easy | Easy | Easy | No |
| Nested Sets | 1 | Hard | Easy | Hard | Hard | Hard | No |
| Closure Table | 2 | Easy | Easy | Easy | Easy | Easy | Yes |

# PHP Demo of Closure Table

# Hierarchical Test Data

- Integrated Taxonomic Information System
  - http://itis.gov/
  - Free authoritative taxonomic information on plants, animals, fungi, microbes
  - 518,756 scientific names (as of Feb 2011)

# California Poppy

| | |
|---|---|
| Kingdom: | *Plantae* |
| Division: | *Tracheobionta* |
| Class: | *Magnoliophyta* |
| Order: | *Magnoliopsida* |
| *unranked*: | *Magnoliidae* |
| *unranked*: | *Papaverales* |
| Family: | *Papaveraceae* |
| Genus: | *Eschscholzia* |
| Species: | *Eschscholzia californica* |

CALIFORNIAN POPPY

(ESCHSCHOLTZIA CALIFORNICA)

Favorite Flowers of Garden and Greenhouse
Edward Step and William Watson 1896

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*id=18956*

CALIFORNIAN POPPY

(ESCHSCHOLTZIA CALIFORNICA)

Favorite Flowers of Garden and Greenhouse
Edward Step and William Watson 1896

# California Poppy: ITIS Entry

```
SELECT * FROM Hierarchy
  WHERE hierarchy_string LIKE ‘%-18956’;
```

| hierarchy_string |
|---|
| 202422-564824-18061-18063-18064-18879-18880-18954-18956 |

# California Poppy: ITIS Entry

```
SELECT * FROM Hierarchy
 WHERE hierarchy_string LIKE ‘%-18956’;
```

| hierarchy_string |
|---|
| 202422-564824-18061-18063-18064-18879-18880-18954-18956 |

*ITIS data uses path enumeration*

*...but I converted it to closure table*

# Hierarchical Data Classes

```
abstract class ZendX_Db_Table_TreeTable
        extends Zend_Db_Table_Abstract
   {
        public function fetchTreeByRoot($rootId, $expand)
        public function fetchBreadcrumbs($leafId)
   }
```

# Hierarchical Data Classes

```
class ZendX_Db_Table_Row_TreeRow
        extends Zend_Db_Table_Row_Abstract
   {
        public function addChildRow($childRow)
        public function getChildren()
   }

class ZendX_Db_Table_Rowset_TreeRowset
        extends Zend_Db_Table_Rowset_Abstract
   {
        public function append($row)
   }
```

# Using TreeTable

```
class ItisTable extends ZendX_Db_Table_TreeTable
    {
            protected $_name = “longnames”;
            protected $_closureName = “treepaths”;
    }

$itis = new ItisTable();
```

# Breadcrumbs

```
$breadcrumbs = $itis->fetchBreadcrumbs(18956);

foreach ($breadcrumbs as $crumb) {
        print $crumb->completename . “ > ”;
  }
```

Plantae > Tracheobionta > Magnoliophyta > Magnoliopsida > Magnoliidae > Papaverales > Papaveraceae > Eschscholzia > Eschscholzia californica >

# Breadcrumbs SQL

```
SELECT a.* FROM longnames AS a
  INNER JOIN treepaths AS c ON a.tsn = c.a
  WHERE (c.d = 18956)
  ORDER BY c.l DESC
```

# How Does it Perform?

- Query profile = 0.0006 sec
- MySQL EXPLAIN:

| table | type | key | ref | rows | extra |
|---|---|---|---|---|---|
| c | ref | tree_dl | const | 9 | Using where; Using index |
| a | eq_ref | primary | c.a | 1 | |

# Dump Tree

```
$tree = $itis->fetchTreeByRoot(18880);  // Papaveraceae

print_tree($tree);


function print_tree($tree, $prefix = ‘’)
    {
      print “{$prefix} {$tree->completename}\n”;
      foreach ($tree->getChildren() as $child) {
        print_tree($child, “{$prefix}   ”);
      }
    }
```

# Dump Tree Result

```
Papaveraceae
  Platystigma
    Platystigma linearis
  Glaucium
    Glaucium corniculatum
    Glaucium flavum
  Chelidonium
    Chelidonium majus
  Bocconia
    Bocconia frutescens
  Stylophorum
    Stylophorum diphyllum
  Stylomecon
    Stylomecon heterophylla
  Canbya
    Canbya aurea
    Canbya candida
  Chlidonium
    Chlidonium majus
```

```
Romneya
    Romneya coulteri
    Romneya trichocalyx
  Dendromecon
    Dendromecon harfordii
    Dendromecon rigida
  Eschscholzia
    Eschscholzia californica
    Eschscholzia glyptosperma
    Eschscholzia hypecoides
    Eschscholzia lemmonii
    Eschscholzia lobbii
    Eschscholzia minutiflora
    Eschscholzia parishii
    Eschscholzia ramosa
    Eschscholzia rhombipetala
    Eschscholzia caespitosa
etc...
```

# Dump Tree SQL

```
SELECT d.*, p.a AS _parent
    FROM treepaths AS c
    INNER JOIN longnames AS d ON c.d = d.tsn
    LEFT JOIN treepaths AS p ON p.d = d.tsn
        AND p.a IN (202422, 564824, 18053, 18020)
        AND p.l = 1
    WHERE (c.a = 202422)
        AND (p.a IS NOT NULL OR d.tsn = 202422)
    ORDER BY c.l, d.completename;
```

# Dump Tree SQL

*show children of these nodes*

```
SELECT d.*, p.a AS _parent
  FROM treepaths AS c
  INNER JOIN longnames AS d ON c.d = d.tsn
  LEFT JOIN treepaths AS p ON p.d = d.tsn
     AND p.a IN (202422, 564824, 18053, 18020)
     AND p.l = 1
  WHERE (c.a = 202422)
     AND (p.a IS NOT NULL OR d.tsn = 202422)
  ORDER BY c.l, d.completename;
```

# How Does it Perform?

- Query profile = 0.20 sec on Macbook Pro
- MySQL EXPLAIN:

| table | type | key | ref | rows | extra |
|---|---|---|---|---|---|
| c | ref | tree_adl | const | 114240 | Using index; Using temporary; Using filesort |
| d | eq_ref | primary | c.d | 1 | |
| p | ref | tree_dl | c.d, const | 1 | Using where; Using index |

# SHOW CREATE TABLE

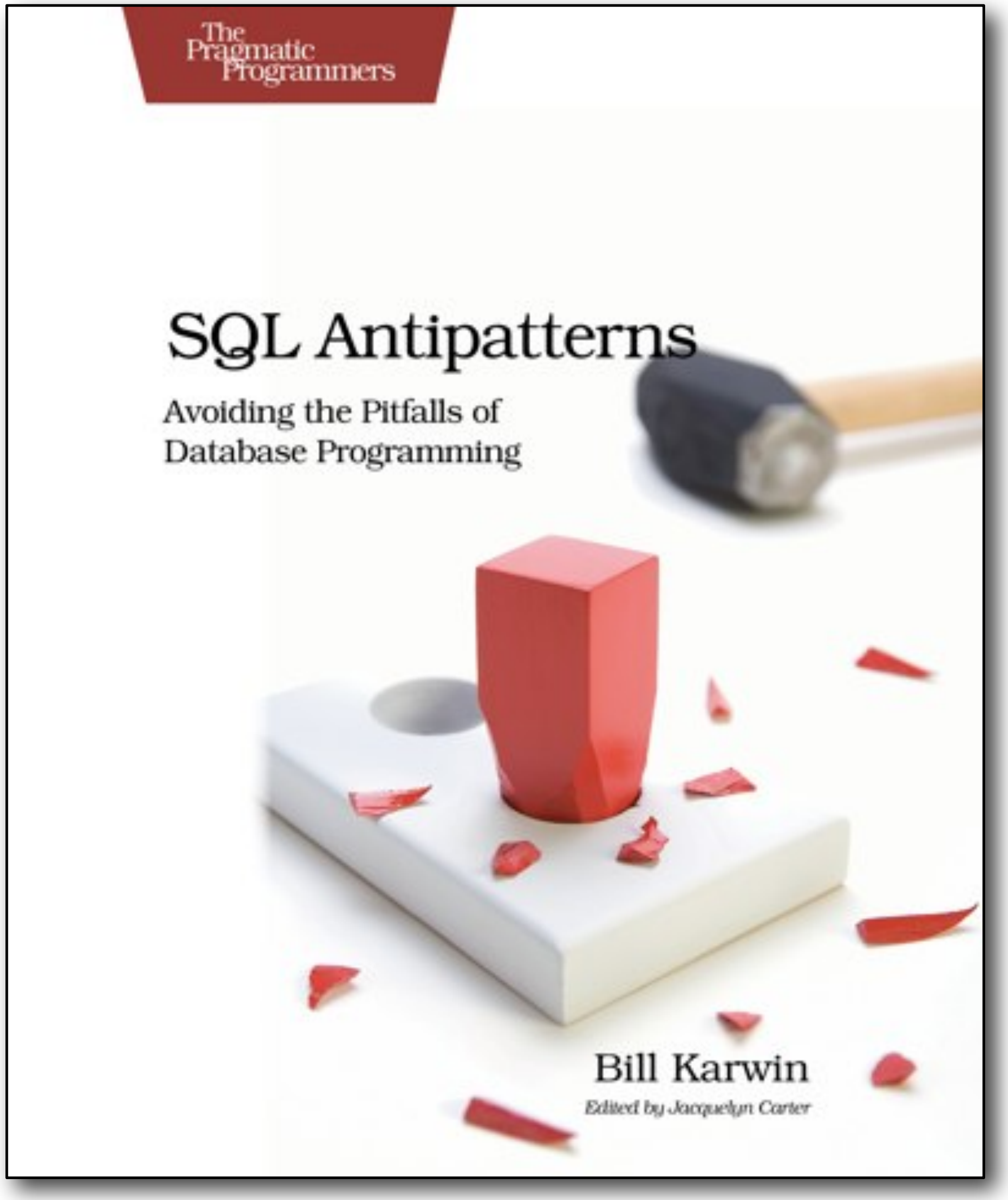
```
CREATE TABLE `treepaths` (
    `a` int(11) NOT NULL DEFAULT '0',
    `d` int(11) NOT NULL DEFAULT '0',
    `l` tinyint(3) unsigned NOT NULL DEFAULT '0',
    PRIMARY KEY (`a`,`d`),
    KEY `tree_adl` (`a`,`d`,`l`),
    KEY `tree_dl` (`d`,`l`),
    CONSTRAINT FOREIGN KEY (`a`)
      REFERENCES `longnames` (`tsn`),
    CONSTRAINT FOREIGN KEY (`d`)
      REFERENCES `longnames` (`tsn`)
  ) ENGINE=InnoDB
```

# SHOW TABLE STATUS

```
Name:            treepaths
  Engine:        InnoDB
  Version:       10
  Row_format:    Compact
  Rows:          4600439
  Avg_row_length: 62
  Data_length:   288276480
  Max_data_length:0
  Index_length:  273137664
  Data_free:     7340032
```

# Demo Time!

# SQL Antipatterns


The Pragmatic Programmers
SQL Antipatterns
Avoiding the Pitfalls of Database Programming
Bill Karwin
Edited by Jacquelyn Carter

http://www.pragprog.com/titles/bksqla/