INFOH417 Database System Architecture

Chess Extension for PostgreSQL

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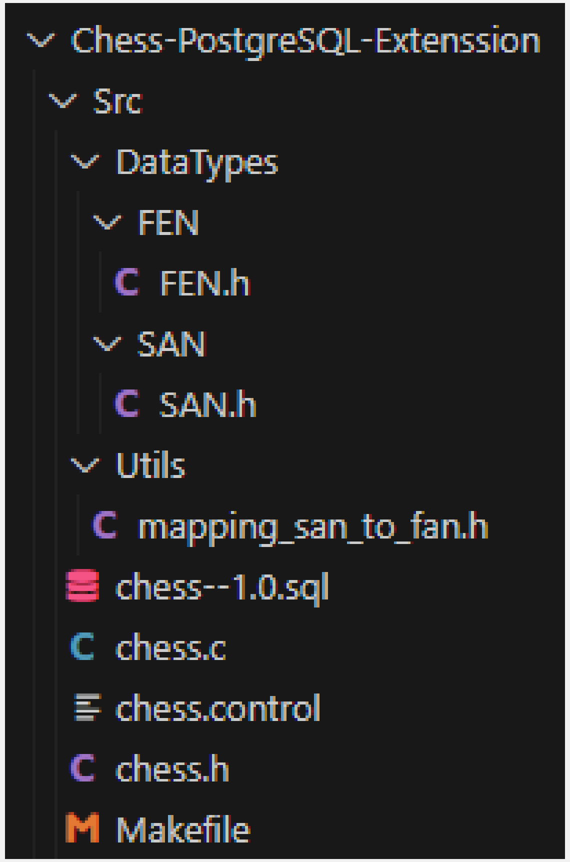
Outline

- Project Structure
- Data types (SAN, FAN)
- Functions (getBoard, getFirstMoves, hasOpening, hasBoard)
- Indexes (Btree for hasOpening, GIN for hasBoard)

Project Structure

- Project Structure
  - Data types: `FEN.h`, `SAN.h`
  - `mapping_san_to_fen.h`: A header containing a utility function `san_to_fan` written with Python embedded code
  - `chess—1.0.sql`, `chess.h`, `chess.c`, `chess.control`: files for defining the Postgres extension named `chess`, version 1.0
  - `makefile`: for installing Postgres extensions

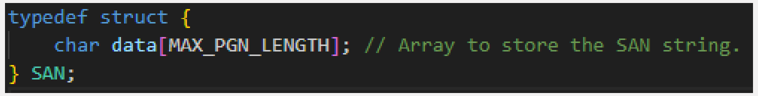


```
Chess-PostgreSQL-Extenssion
  Src
    DataTypes
      FEN
        FEN.h
      SAN
        SAN.h
    Utils
      mapping_san_to_fan.h
  chess--1.0.sql
  chess.c
  chess.control
  chess.h
  Makefile
```

Data Types

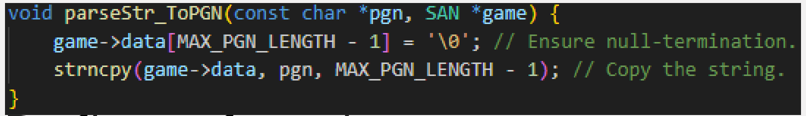
Standard Algebraic Notation (SAN)

1. Define the SAN type with struct

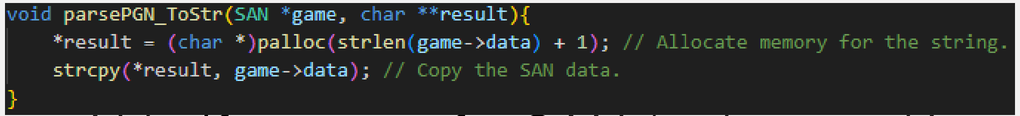


```c
typedef struct {
    char data[MAX_PGN_LENGTH]; // Array to store the SAN string.
} SAN;
```

2. Define two functions `parseStr_ToPGN` and `parsePGN_ToStr` to convert a string (written in SAN format) to SAN data type and vice versa.

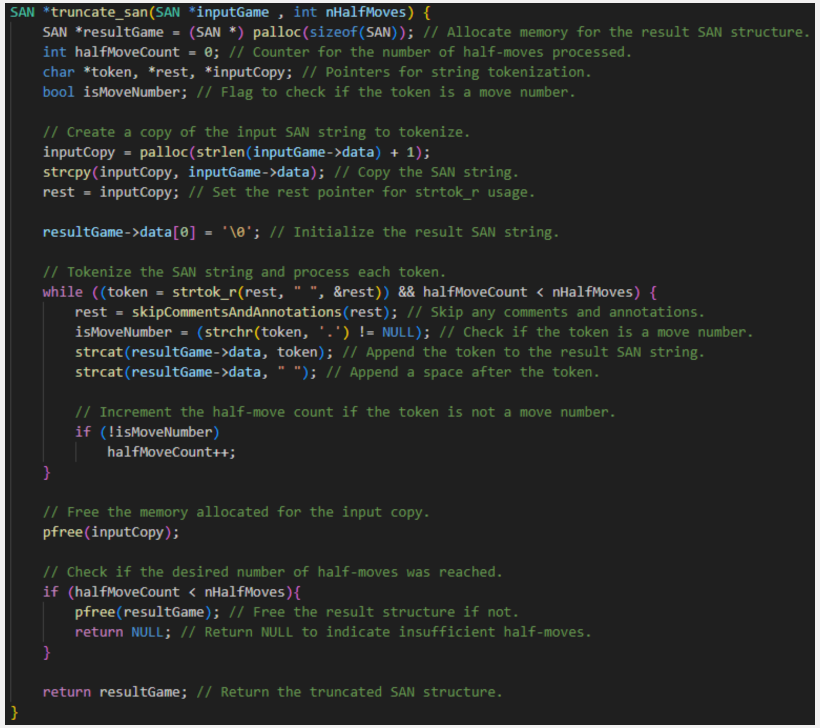


```c
void parseStr_ToPGN(const char *pgn, SAN *game) {
    game->data[MAX_PGN_LENGTH - 1] = '\0'; // Ensure null-termination.
    strncpy(game->data, pgn, MAX_PGN_LENGTH - 1); // Copy the string.
}
```



```c
void parsePGN_ToStr(SAN *game, char **result){
    *result = (char *)palloc(strlen(game->data) + 1); // Allocate memory for the string.
    strcpy(*result, game->data); // Copy the SAN data.
}
```

3. Define a function `truncate_san` to get N half moves of a SAN (to be used in `getFirstMoves` function)
   Idea:
   - Loop over the input SAN
   - Append the SAN token to result
   - Count the half moves
   - Stop when reaching the desired n half moves.

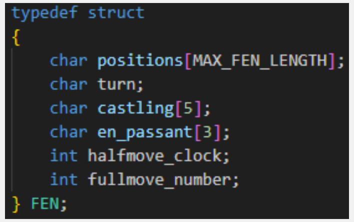


```c
SAN *truncate_san(SAN *inputGame , int nHalfMoves) {
    SAN *resultGame = (SAN *) palloc(sizeof(SAN)); // Allocate memory for the result SAN structure.
    int halfMoveCount = 0; // Counter for the number of half-moves processed.
    char *token, *rest, *inputCopy; // Pointers for string tokenization.
    bool isMoveNumber; // Flag to check if the token is a move number.

    // Create a copy of the input SAN string to tokenize.
    inputCopy = palloc(strlen(inputGame->data) + 1);
    strcpy(inputCopy, inputGame->data); // Copy the SAN string.
    rest = inputCopy; // Set the rest pointer for strtok_r usage.

    resultGame->data[0] = '\0'; // Initialize the result SAN string.

    // Tokenize the SAN string and process each token.
    while ((token = strtok_r(rest, " ", &rest)) && halfMoveCount < nHalfMoves) {
        rest = skipCommentsAndAnnotations(rest); // Skip any comments and annotations.
        isMoveNumber = (strchr(token, '.') != NULL); // Check if the token is a move number.
        strcat(resultGame->data, token); // Append the token to the result SAN string.
        strcat(resultGame->data, " "); // Append a space after the token.

        // Increment the half-move count if the token is not a move number.
        if (!isMoveNumber)
            halfMoveCount++;
    }

    // Free the memory allocated for the input copy.
    pfree(inputCopy);

    // Check if the desired number of half-moves was reached.
    if (halfMoveCount < nHalfMoves){
        pfree(resultGame); // Free the result structure if not.
        return NULL; // Return NULL to indicate insufficient half-moves.
    }

    return resultGame; // Return the truncated SAN structure.
}
```

Data Types

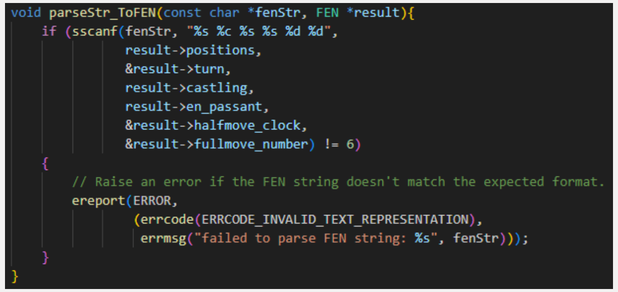
Forsyth–Edwards Notation (FEN)

1. Define the FANtype with struct

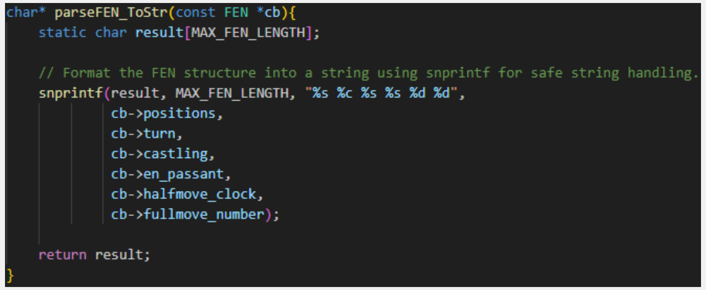


```c
typedef struct
{
    char positions[MAX_FEN_LENGTH];
    char turn;
    char castling[5];
    char en_passant[3];
    int halfmove_clock;
    int fullmove_number;
} FEN;
```

2. Define two functions `parseStr_ToFEN` and `parseFEN_ToStr` to convert a string (written in FEN format) to FEN data type and vice versa.

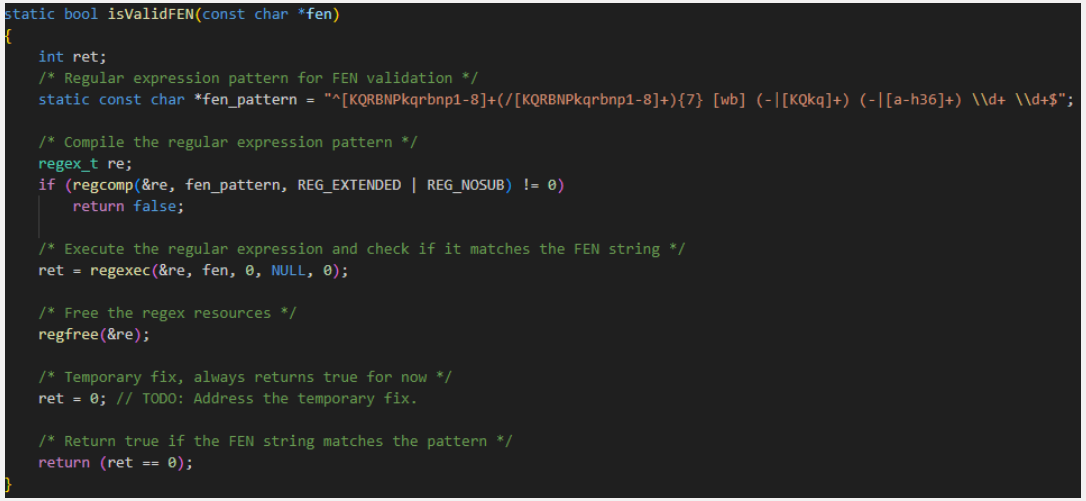


```c
void parseStr_ToFEN(const char *fenStr, FEN *result){
    if (sscanf(fenStr, "%s %c %s %s %d %d",
                result->positions,
                &result->turn,
                result->castling,
                result->en_passant,
                &result->halfmove_clock,
                &result->fullmove_number) != 6)
    {
        // Raise an error if the FEN string doesn't match the expected format.
        ereport(ERROR,
                 (errcode(ERRCODE_INVALID_TEXT_REPRESENTATION),
                  errmsg("failed to parse FEN string: %s", fenStr)));
    }
}
```



```c
char* parseFEN_ToStr(const FEN *cb){
    static char result[MAX_FEN_LENGTH];

    // Format the FEN structure into a string using snprintf for safe string handling.
    snprintf(result, MAX_FEN_LENGTH, "%s %c %s %s %d %d",
                cb->positions,
                cb->turn,
                cb->castling,
                cb->en_passant,
                cb->halfmove_clock,
                cb->fullmove_number);

    return result;
}
```

3. Define a function `isvalidFEN` to check if the input string has the FEN format



```c
static bool isValidFEN(const char *fen)
{
    int ret;
    /* Regular expression pattern for FEN validation */
    static const char *fen_pattern = "^[KQRBNPkqrbnp1-8]+(/[KQRBNPkqrbnp1-8]+){7} [wb] (-|[KQkq]+) (-|[a-h36]+) \\d+ \\d+$";

    /* Compile the regular expression pattern */
    regex_t re;
    if (regcomp(&re, fen_pattern, REG_EXTENDED | REG_NOSUB) != 0)
        return false;

    /* Execute the regular expression and check if it matches the FEN string */
    ret = regexec(&re, fen, 0, NULL, 0);

    /* Free the regex resources */
    regfree(&re);

    /* Temporary fix, always returns true for now */
    ret = 0; // TODO: Address the temporary fix.

    /* Return true if the FEN string matches the pattern */
    return (ret == 0);
}
```

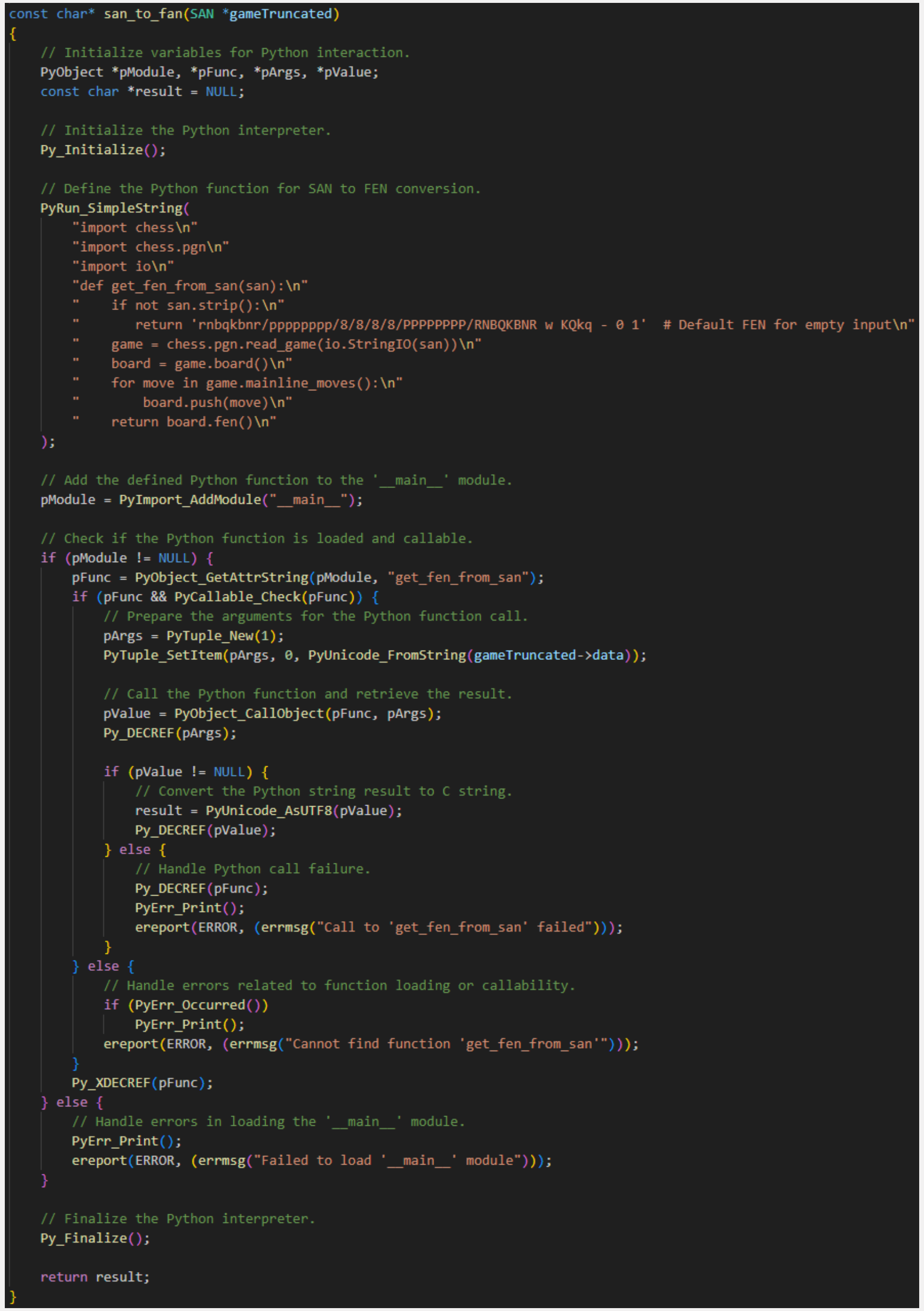
Functions

Utility function `san_to_fen`

Input: (SAN) gamegame
Output: (FEN) chessboard

Idea:

- Use a Python library named `chess` (installed with `pip install chess`) to convert SAN to FEN.
- Declare `#include <python3.11/Python.h>` to use Python embedded code in C code.
- Write the Python embedded code with `PyRun_SimpleString`, in which we define a function `get_fen_from_san`.
- In the main C code, get the Python function using `PyObject_GetAttrString`.
- Get the result using `PyObject_CallObject`, then convert to C string using `PyUnicode_AsUTF8`



```c
const char* san_to_fan(SAN *gameTruncated)
{
    // Initialize variables for Python interaction.
    PyObject *pModule, *pFunc, *pArgs, *pValue;
    const char *result = NULL;

    // Initialize the Python interpreter.
    Py_Initialize();

    // Define the Python function for SAN to FEN conversion.
    PyRun_SimpleString(
        "import chess\n"
        "import chess.pgn\n"
        "import io\n"
        "def get_fen_from_san(san):\n"
        "    if not san.strip():\n"
        "       return 'rnbqkbnr/pppppppp/8/8/8/8/PPPPPPPP/RNBQKBNR w KQkq - 0 1'  # Default FEN for empty input\n"
        "    game = chess.pgn.read_game(io.StringIO(san))\n"
        "    board = game.board()\n"
        "    for move in game.mainline_moves():\n"
        "        board.push(move)\n"
        "    return board.fen()\n"
    );

    // Add the defined Python function to the '__main__' module.
    pModule = PyImport_AddModule("__main__");

    // Check if the Python function is loaded and callable.
    if (pModule != NULL) {
        pFunc = PyObject_GetAttrString(pModule, "get_fen_from_san");
        if (pFunc && PyCallable_Check(pFunc)) {
            // Prepare the arguments for the Python function call.
            pArgs = PyTuple_New(1);
            PyTuple_SetItem(pArgs, 0, PyUnicode_FromString(gameTruncated->data));

            // Call the Python function and retrieve the result.
            pValue = PyObject_CallObject(pFunc, pArgs);
            Py_DECREF(pArgs);

            if (pValue != NULL) {
                // Convert the Python string result to C string.
                result = PyUnicode_AsUTF8(pValue);
                Py_DECREF(pValue);
            } else {
                // Handle Python call failure.
                Py_DECREF(pFunc);
                PyErr_Print();
                ereport(ERROR, (errmsg("Call to 'get_fen_from_san' failed")));
            }
        } else {
            // Handle errors related to function loading or callability.
            if (PyErr_Occurred())
                PyErr_Print();
            ereport(ERROR, (errmsg("Cannot find function 'get_fen_from_san'")));
        }
        Py_XDECREF(pFunc);
    } else {
        // Handle errors in loading the '__main__' module.
        PyErr_Print();
        ereport(ERROR, (errmsg("Failed to load '__main__' module")));
    }

    // Finalize the Python interpreter.
    Py_Finalize();

    return result;
}
```

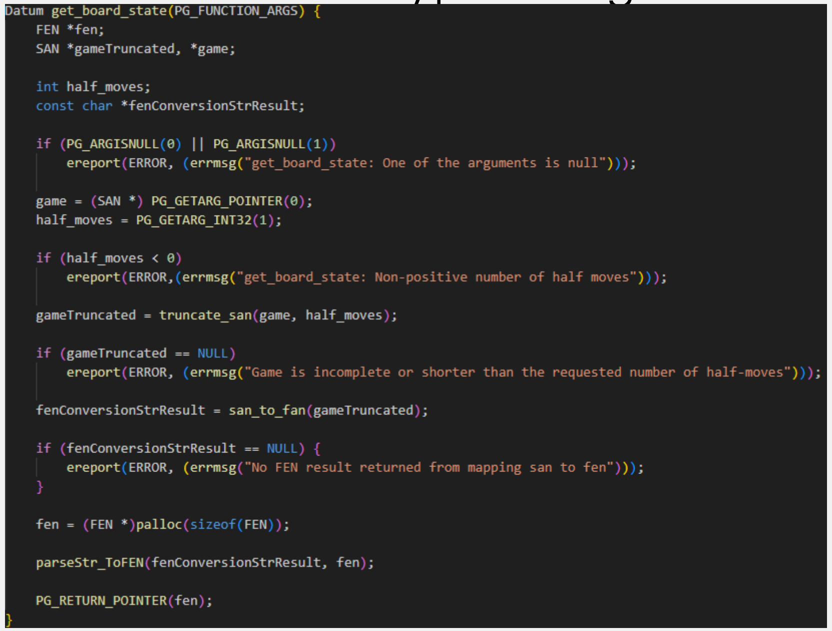
Functions

getBoard (`get_board_state`)

Input:
- (SAN) chessgame
- (int) N: number of half moves

Output:
- (FEN) board state after N half moves

Idea:
- Use the function `truncate_san` (defined in SAN.h) to get the truncated SAN afer N half moves
- Convert to FEN type using the function `san_to_fan` (defined in `mapping_san_to_fan.h`)



```c
Datum get_board_state(PG_FUNCTION_ARGS) {
    FEN *fen;
    SAN *gameTruncated, *game;

    int half_moves;
    const char *fenConversionStrResult;

    if (PG_ARGISNULL(0) || PG_ARGISNULL(1))
        ereport(ERROR, (errmsg("get_board_state: One of the arguments is null")));

    game = (SAN *) PG_GETARG_POINTER(0);
    half_moves = PG_GETARG_INT32(1);

    if (half_moves < 0)
        ereport(ERROR,(errmsg("get_board_state: Non-positive number of half moves")));

    gameTruncated = truncate_san(game, half_moves);

    if (gameTruncated == NULL)
        ereport(ERROR, (errmsg("Game is incomplete or shorter than the requested number of half-moves")));

    fenConversionStrResult = san_to_fan(gameTruncated);

    if (fenConversionStrResult == NULL) {
        ereport(ERROR, (errmsg("No FEN result returned from mapping san to fen")));
    }

    fen = (FEN *)palloc(sizeof(FEN));

    parseStr_ToFEN(fenConversionStrResult, fen);

    PG_RETURN_POINTER(fen);
}
```

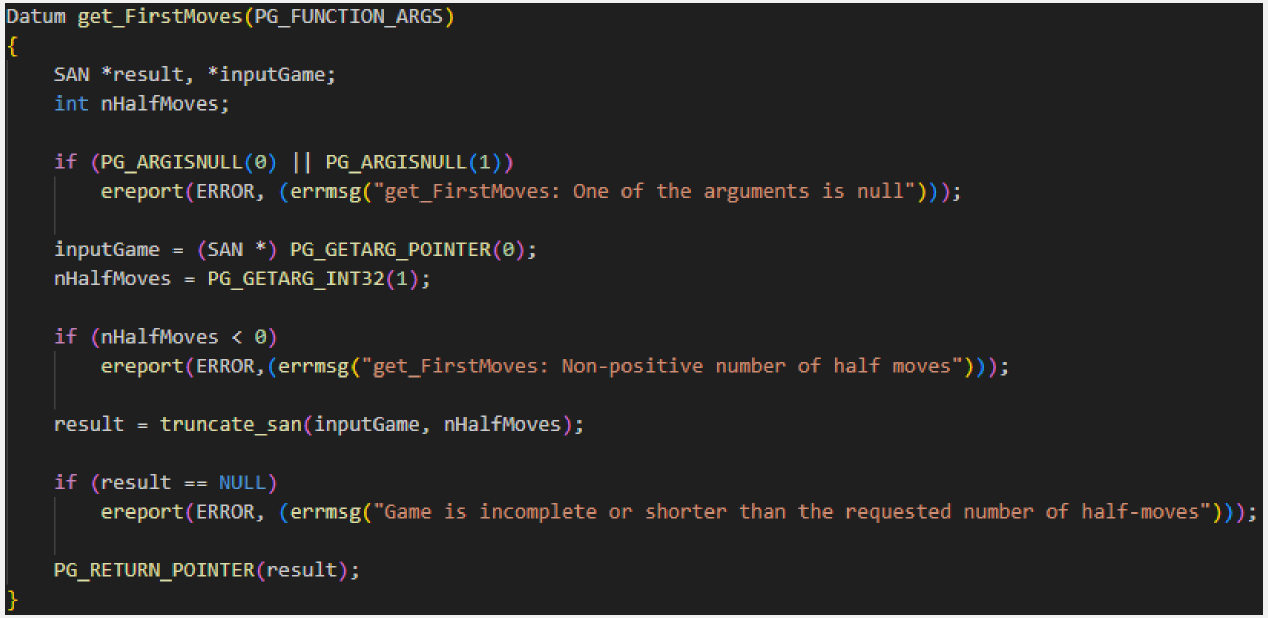
Functions

getFirstMoves (`get_firstMoves`)

Input:
- (SAN) chessgame
- (int) N: number of half moves

Output:
- (SAN) chessgame after N half moves

Idea:
- Similar to the function `get_board_state`, but do not need to convert the result to FEN.
- Return the output right after using the function `truncate_san`.



```
Datum get_FirstMoves(PG_FUNCTION_ARGS)
{
    SAN *result, *inputGame;
    int nHalfMoves;

    if (PG_ARGISNULL(0) || PG_ARGISNULL(1))
        ereport(ERROR, (errmsg("get_FirstMoves: One of the arguments is null")));

    inputGame = (SAN *) PG_GETARG_POINTER(0);
    nHalfMoves = PG_GETARG_INT32(1);

    if (nHalfMoves < 0)
        ereport(ERROR,(errmsg("get_FirstMoves: Non-positive number of half moves")));

    result = truncate_san(inputGame, nHalfMoves);

    if (result == NULL)
        ereport(ERROR, (errmsg("Game is incomplete or shorter than the requested number of half-moves")));

    PG_RETURN_POINTER(result);
}
```

Functions

hasOpening (**`has_opening`**)

Input:

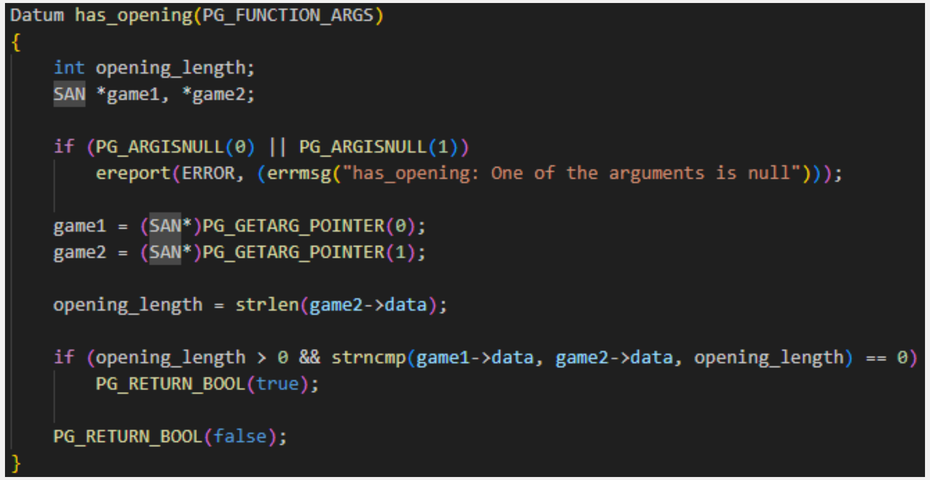
- (SAN) chessgame 1
- (SAN) chessgame 2

Output:

- (boolean) **True** if chessgame 1 starts with the same set of moves as chessgame 2.

Idea:

- Use the C built-in function `strncmp` to compare chessgame 1 with chessgame 2 in terms of beginning moves, where the compared string length is the length of chessgame 2.
- Get **True** if chessgame 2 is included in the beginning moves of chessgame 1.



```
Datum has_opening(PG_FUNCTION_ARGS)
{
    int opening_length;
    SAN *game1, *game2;

    if (PG_ARGISNULL(0) || PG_ARGISNULL(1))
        ereport(ERROR, (errmsg("has_opening: One of the arguments is null")));

    game1 = (SAN*)PG_GETARG_POINTER(0);
    game2 = (SAN*)PG_GETARG_POINTER(1);

    opening_length = strlen(game2->data);

    if (opening_length > 0 && strncmp(game1->data, game2->data, opening_length) == 0)
        PG_RETURN_BOOL(true);

    PG_RETURN_BOOL(false);
}
```

Functions

hasBoard (`has_Board`)

Input:

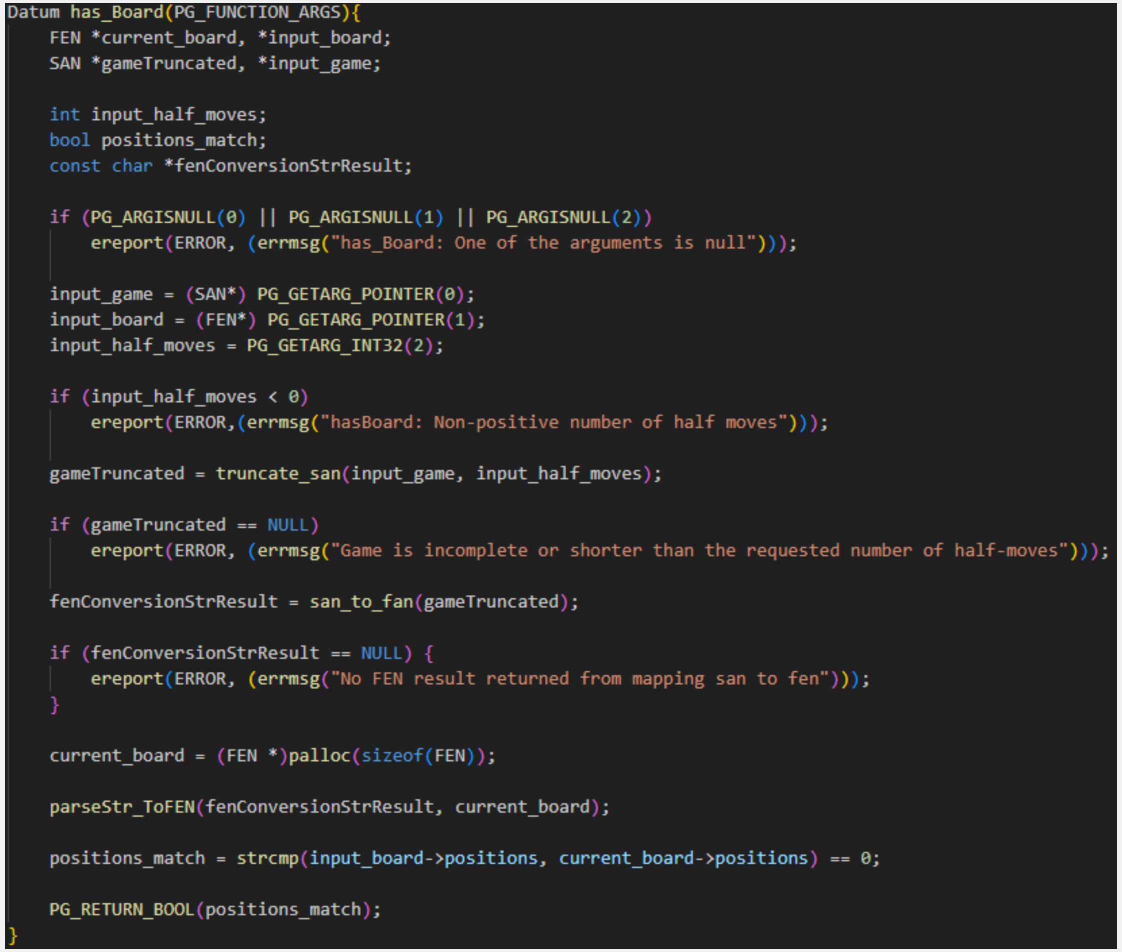
- (SAN) chessgame
- (FEN) chessboard
- (int) N half moves

Output:

- (boolean) **True** if chessgame contains chessboard in its first N half-moves.

Idea:

- Truncate the chessgame after N half moves with the function `truncate_san`.
- Convert to FEN with the function `san_to_fen`
- Use the C built-in function `strcmp` to compare the converted FEN with input chessboard
- Get **True** if they are the same



```c
Datum has_Board(PG_FUNCTION_ARGS){
    FEN *current_board, *input_board;
    SAN *gameTruncated, *input_game;

    int input_half_moves;
    bool positions_match;
    const char *fenConversionStrResult;

    if (PG_ARGISNULL(0) || PG_ARGISNULL(1) || PG_ARGISNULL(2))
        ereport(ERROR, (errmsg("has_Board: One of the arguments is null")));

    input_game = (SAN*) PG_GETARG_POINTER(0);
    input_board = (FEN*) PG_GETARG_POINTER(1);
    input_half_moves = PG_GETARG_INT32(2);

    if (input_half_moves < 0)
        ereport(ERROR,(errmsg("hasBoard: Non-positive number of half moves")));

    gameTruncated = truncate_san(input_game, input_half_moves);

    if (gameTruncated == NULL)
        ereport(ERROR, (errmsg("Game is incomplete or shorter than the requested number of half-moves")));

    fenConversionStrResult = san_to_fan(gameTruncated);

    if (fenConversionStrResult == NULL) {
        ereport(ERROR, (errmsg("No FEN result returned from mapping san to fen")));
    }

    current_board = (FEN *)palloc(sizeof(FEN));

    parseStr_ToFEN(fenConversionStrResult, current_board);

    positions_match = strcmp(input_board->positions, current_board->positions) == 0;

    PG_RETURN_BOOL(positions_match);
}
```

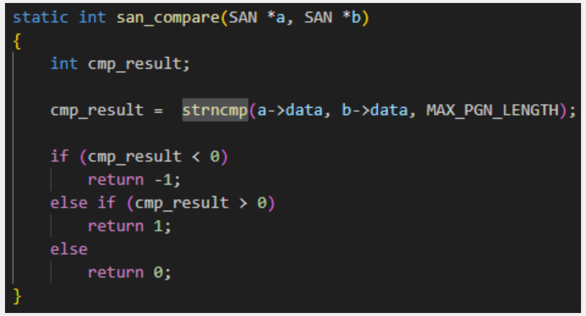
Indexes

B-Tree Index

6 operations: less than (`san_lt`), equal (san_eq), greater than (san_gt), comparator (san_cmp), like (san_like), not like (san_not_like)

Beforehand, define a utility function `san_compare` to compare two SAN strings
Input: (SAN) a, (SAN), b
Output: (int) -1, 0, or 1

Idea: Simply use the C built-in function strncmp to compare two SAN strings, where MAX_PGN_LENGTH is a pre-defined variable.



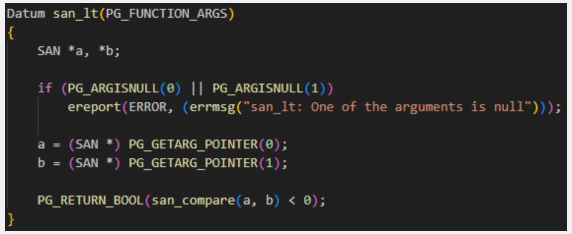
```c
static int san_compare(SAN *a, SAN *b)
{
    int cmp_result;

    cmp_result =  strncmp(a->data, b->data, MAX_PGN_LENGTH);

    if (cmp_result < 0)
        return -1;
    else if (cmp_result > 0)
        return 1;
    else
        return 0;
}
```

This function will be used in B-tree operations.

Indexes

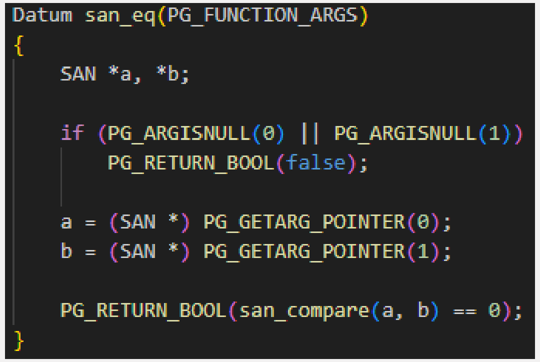
B-Tree Index

`san_lt`
Input: (SAN) a, (SAN), b
Output: (boolean) **True** if SAN string a is less than SAN string b
Get the result by checking if the returned value of `san_compare(a, b)` is less than 0



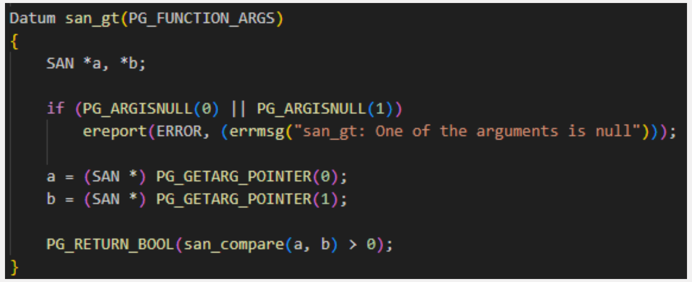
```
Datum san_lt(PG_FUNCTION_ARGS)
{
    SAN *a, *b;

    if (PG_ARGISNULL(0) || PG_ARGISNULL(1))
        ereport(ERROR, (errmsg("san_lt: One of the arguments is null")));

    a = (SAN *) PG_GETARG_POINTER(0);
    b = (SAN *) PG_GETARG_POINTER(1);

    PG_RETURN_BOOL(san_compare(a, b) < 0);
}
```

`san_eq`
The same as `san_lt`, except that the checking condition is equal to 0



```
Datum san_eq(PG_FUNCTION_ARGS)
{
    SAN *a, *b;

    if (PG_ARGISNULL(0) || PG_ARGISNULL(1))
        PG_RETURN_BOOL(false);

    a = (SAN *) PG_GETARG_POINTER(0);
    b = (SAN *) PG_GETARG_POINTER(1);

    PG_RETURN_BOOL(san_compare(a, b) == 0);
}
```

`san_gt`
The same as `san_lt`, except that the checking condition is greater than 0

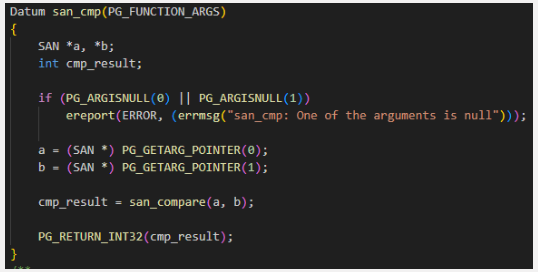


```
Datum san_gt(PG_FUNCTION_ARGS)
{
    SAN *a, *b;

    if (PG_ARGISNULL(0) || PG_ARGISNULL(1))
        ereport(ERROR, (errmsg("san_gt: One of the arguments is null")));

    a = (SAN *) PG_GETARG_POINTER(0);
    b = (SAN *) PG_GETARG_POINTER(1);

    PG_RETURN_BOOL(san_compare(a, b) > 0);
}
```

Indexes

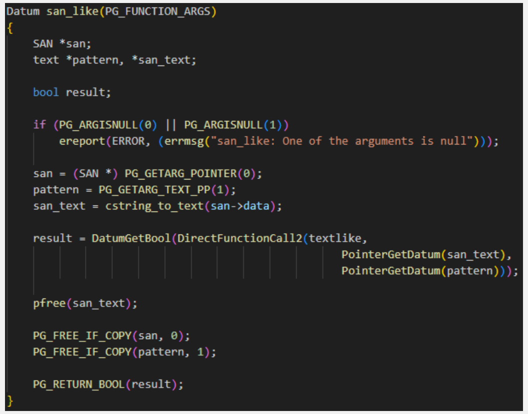
B-Tree Index

`san_cmp`
Get the result directly from the returned value of the function `san_compare(a, b)`



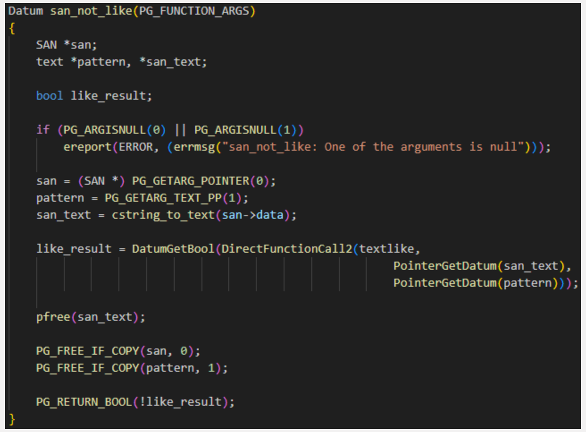
```c
Datum san_cmp(PG_FUNCTION_ARGS)
{
    SAN *a, *b;
    int cmp_result;

    if (PG_ARGISNULL(0) || PG_ARGISNULL(1))
        ereport(ERROR, (errmsg("san_cmp: One of the arguments is null")));

    a = (SAN *) PG_GETARG_POINTER(0);
    b = (SAN *) PG_GETARG_POINTER(1);

    cmp_result = san_compare(a, b);

    PG_RETURN_INT32(cmp_result);
}
```

`san_like`
Use Postgres built-in function DirectFunctionCall2 (defined in fmgr.h) to call the function textlike, taking



```c
Datum san_like(PG_FUNCTION_ARGS)
{
    SAN *san;
    text *pattern, *san_text;

    bool result;

    if (PG_ARGISNULL(0) || PG_ARGISNULL(1))
        ereport(ERROR, (errmsg("san_like: One of the arguments is null")));

    san = (SAN *) PG_GETARG_POINTER(0);
    pattern = PG_GETARG_TEXT_PP(1);
    san_text = cstring_to_text(san->data);

    result = DatumGetBool(DirectFunctionCall2(textlike,
                                              PointerGetDatum(san_text),
                                              PointerGetDatum(pattern)));

    pfree(san_text);

    PG_FREE_IF_COPY(san, 0);
    PG_FREE_IF_COPY(pattern, 1);

    PG_RETURN_BOOL(result);
}
```

`san_not_like`
The same as `san_like,` but return negation.



```c
Datum san_not_like(PG_FUNCTION_ARGS)
{
    SAN *san;
    text *pattern, *san_text;

    bool like_result;

    if (PG_ARGISNULL(0) || PG_ARGISNULL(1))
        ereport(ERROR, (errmsg("san_not_like: One of the arguments is null")));

    san = (SAN *) PG_GETARG_POINTER(0);
    pattern = PG_GETARG_TEXT_PP(1);
    san_text = cstring_to_text(san->data);

    like_result = DatumGetBool(DirectFunctionCall2(textlike,
                                                   PointerGetDatum(san_text),
                                                   PointerGetDatum(pattern)));

    pfree(san_text);

    PG_FREE_IF_COPY(san, 0);
    PG_FREE_IF_COPY(pattern, 1);

    PG_RETURN_BOOL(!like_result);
}
```

Indexes

GIN Index

The idea behind this GIN index is indexing and querying on chess game positions by extending the GIN index for the chess game type.

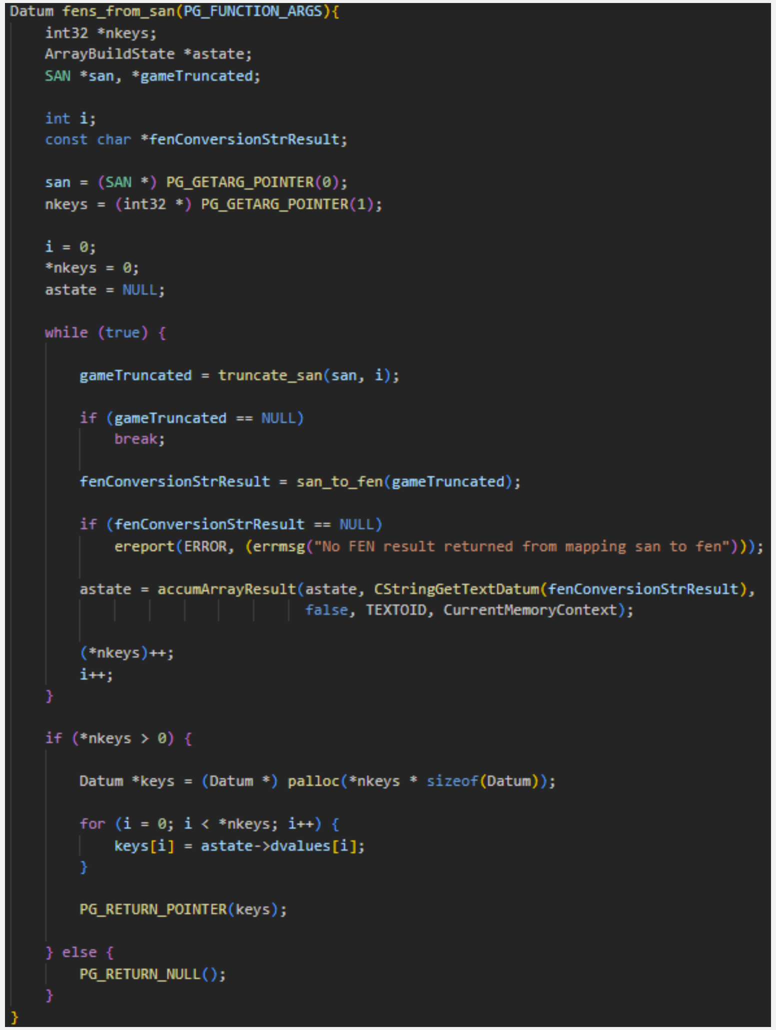
8 functions to try to implement this index:

`fens_from_san`

Extracts FEN strings from a SAN representation of a chess game

Input: (SAN) chessgame

Output: (FEN) chessboard



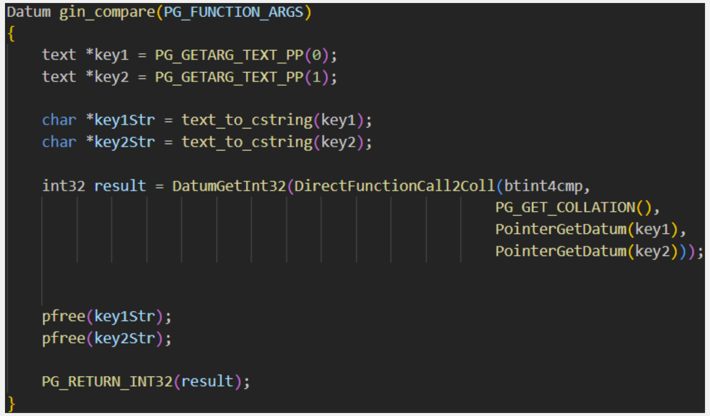
```
Datum fens_from_san(PG_FUNCTION_ARGS){
    int32 *nkeys;
    ArrayBuildState *astate;
    SAN *san, *gameTruncated;

    int i;
    const char *fenConversionStrResult;

    san = (SAN *) PG_GETARG_POINTER(0);
    nkeys = (int32 *) PG_GETARG_POINTER(1);

    i = 0;
    *nkeys = 0;
    astate = NULL;

    while (true) {

        gameTruncated = truncate_san(san, i);

        if (gameTruncated == NULL)
            break;

        fenConversionStrResult = san_to_fen(gameTruncated);

        if (fenConversionStrResult == NULL)
            ereport(ERROR, (errmsg("No FEN result returned from mapping san to fen")));

        astate = accumArrayResult(astate, CStringGetTextDatum(fenConversionStrResult),
                                  false, TEXTOID, CurrentMemoryContext);

        (*nkeys)++;
        i++;
    }

    if (*nkeys > 0) {

        Datum *keys = (Datum *) palloc(*nkeys * sizeof(Datum));

        for (i = 0; i < *nkeys; i++) {
            keys[i] = astate->dvalues[i];
        }

        PG_RETURN_POINTER(keys);

    } else {
        PG_RETURN_NULL();
    }
}
```

`gin_compare`

Compares two text values for GIN indexing

Input: Two text values (keys)

Output: (int) -1, 0, or 1 for the ordering of the two keys.

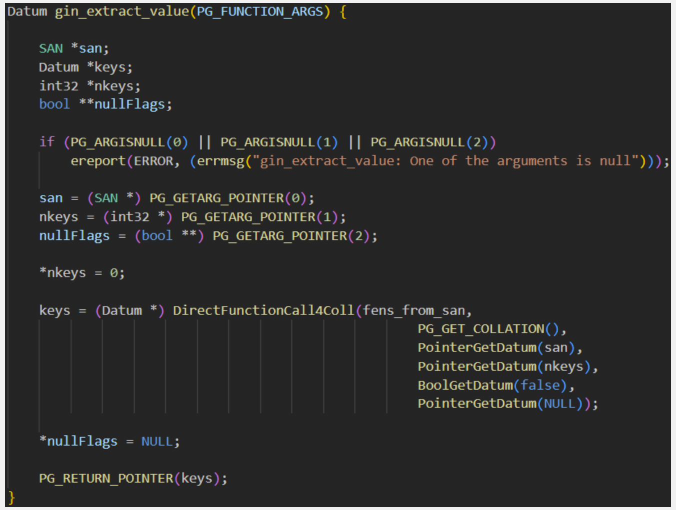


```
Datum gin_compare(PG_FUNCTION_ARGS)
{
    text *key1 = PG_GETARG_TEXT_PP(0);
    text *key2 = PG_GETARG_TEXT_PP(1);

    char *key1Str = text_to_cstring(key1);
    char *key2Str = text_to_cstring(key2);

    int32 result = DatumGetInt32(DirectFunctionCall2Coll(btint4cmp,
                                                        PG_GET_COLLATION(),
                                                        PointerGetDatum(key1),
                                                        PointerGetDatum(key2)));


    pfree(key1Str);
    pfree(key2Str);

    PG_RETURN_INT32(result);
}
```

Indexes

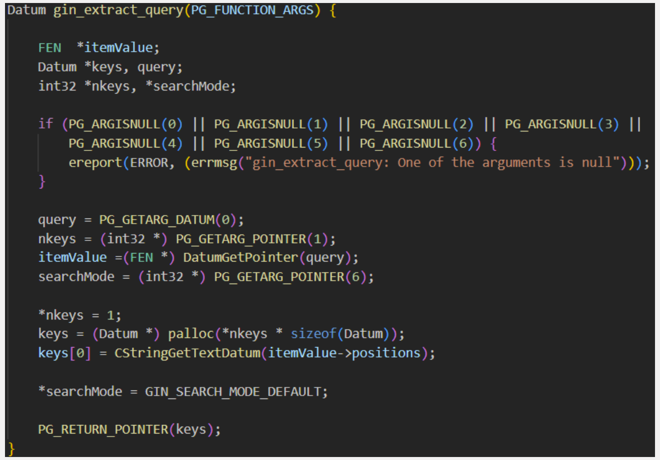
GIN Index

`gin_extract_value`
Prepares indexable keys for GIN indexing from a SAN
Input: (SAN) chessgame
Output: Array of keys (Datum)



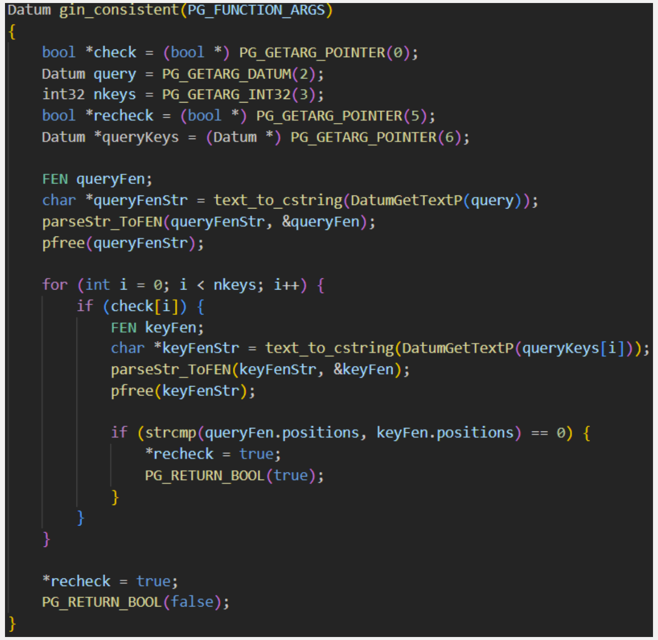
```
Datum gin_extract_value(PG_FUNCTION_ARGS) {

    SAN *san;
    Datum *keys;
    int32 *nkeys;
    bool **nullFlags;

    if (PG_ARGISNULL(0) || PG_ARGISNULL(1) || PG_ARGISNULL(2))
        ereport(ERROR, (errmsg("gin_extract_value: One of the arguments is null")));

    san = (SAN *) PG_GETARG_POINTER(0);
    nkeys = (int32 *) PG_GETARG_POINTER(1);
    nullFlags = (bool **) PG_GETARG_POINTER(2);

    *nkeys = 0;

    keys = (Datum *) DirectFunctionCall4Coll(fens_from_san,
                                                    PG_GET_COLLATION(),
                                                    PointerGetDatum(san),
                                                    PointerGetDatum(nkeys),
                                                    BoolGetDatum(false),
                                                    PointerGetDatum(NULL));

    *nullFlags = NULL;

    PG_RETURN_POINTER(keys);
}
```

`gin_extract_query`
Extracts a query key from a FEN type for GIN indexing searches
Input: (FEN) chessboard, array of keys (Datum), search mode
Output: Array of keys (Datum)



```
Datum gin_extract_query(PG_FUNCTION_ARGS) {

    FEN  *itemValue;
    Datum *keys, query;
    int32 *nkeys, *searchMode;

    if (PG_ARGISNULL(0) || PG_ARGISNULL(1) || PG_ARGISNULL(2) || PG_ARGISNULL(3) ||
        PG_ARGISNULL(4) || PG_ARGISNULL(5) || PG_ARGISNULL(6)) {
        ereport(ERROR, (errmsg("gin_extract_query: One of the arguments is null")));
    }

    query = PG_GETARG_DATUM(0);
    nkeys = (int32 *) PG_GETARG_POINTER(1);
    itemValue =(FEN *) DatumGetPointer(query);
    searchMode = (int32 *) PG_GETARG_POINTER(6);

    *nkeys = 1;
    keys = (Datum *) palloc(*nkeys * sizeof(Datum));
    keys[0] = CStringGetTextDatum(itemValue->positions);

    *searchMode = GIN_SEARCH_MODE_DEFAULT;

    PG_RETURN_POINTER(keys);
}
```

`gin_consistent`
Checks if indexed keys are consistent with a query key in GIN index searches
Input: (Boolean Array) check, (Query Key) query, (Number of Keys) nkeys, (Recheck Flag) recheck, (Array of Query Keys) queryKeys
Output: (Boolean) True if the result of the comparison between the query key and indexed keys is less than 0; otherwise, False



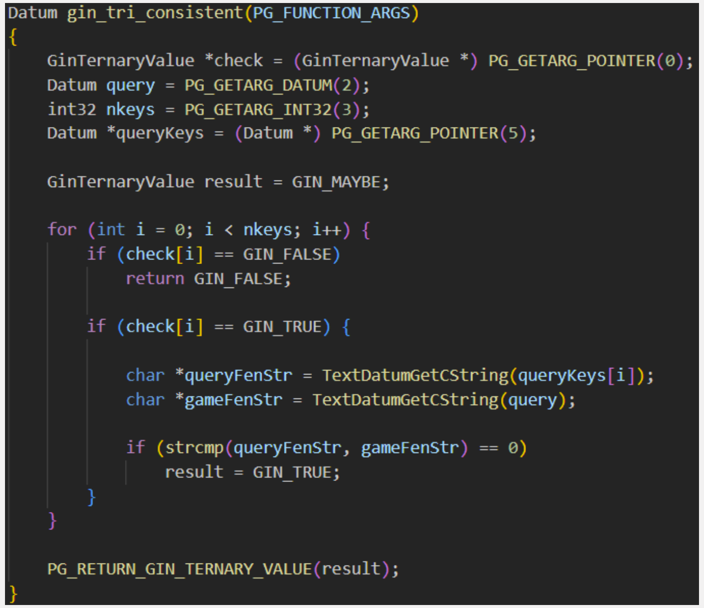
```
Datum gin_consistent(PG_FUNCTION_ARGS)
{
    bool *check = (bool *) PG_GETARG_POINTER(0);
    Datum query = PG_GETARG_DATUM(2);
    int32 nkeys = PG_GETARG_INT32(3);
    bool *recheck = (bool *) PG_GETARG_POINTER(5);
    Datum *queryKeys = (Datum *) PG_GETARG_POINTER(6);

    FEN queryFen;
    char *queryFenStr = text_to_cstring(DatumGetTextP(query));
    parseStr_ToFEN(queryFenStr, &queryFen);
    pfree(queryFenStr);

    for (int i = 0; i < nkeys; i++) {
        if (check[i]) {
            FEN keyFen;
            char *keyFenStr = text_to_cstring(DatumGetTextP(queryKeys[i]));
            parseStr_ToFEN(keyFenStr, &keyFen);
            pfree(keyFenStr);

            if (strcmp(queryFen.positions, keyFen.positions) == 0) {
                *recheck = true;
                PG_RETURN_BOOL(true);
            }
        }
    }

    *recheck = true;
    PG_RETURN_BOOL(false);
}
```

Indexes

GIN Index

`gin_tri_consistent`

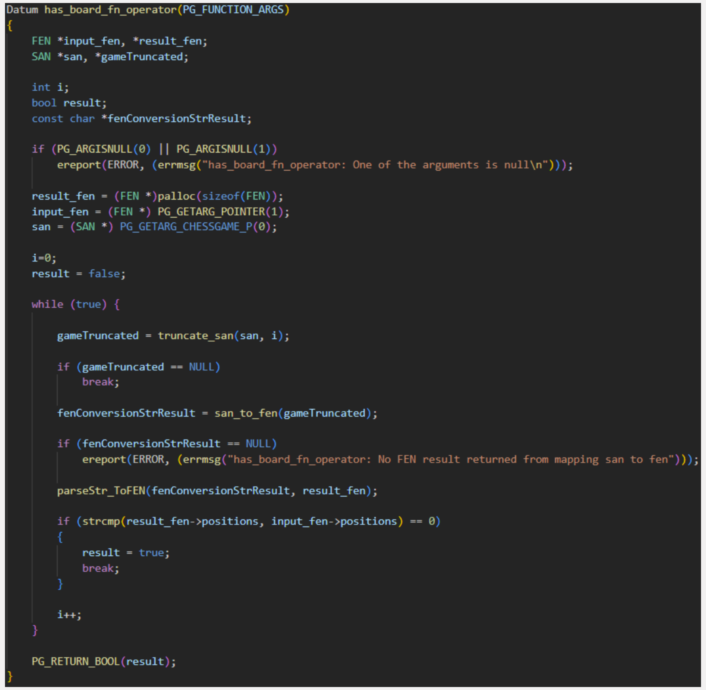
Performs a ternary consistency check for GIN index operations
Input: (Array of Ternary Values) check, (Query Key) query, Number of Keys) nkeys, (Array of Query Keys) queryKeys
Output: (Boolean) True if the result of `the` comparison between the query key and indexed keys is less than 0; otherwise, False.



```
Datum gin_tri_consistent(PG_FUNCTION_ARGS)
{
    GinTernaryValue *check = (GinTernaryValue *) PG_GETARG_POINTER(0);
    Datum query = PG_GETARG_DATUM(2);
    int32 nkeys = PG_GETARG_INT32(3);
    Datum *queryKeys = (Datum *) PG_GETARG_POINTER(5);

    GinTernaryValue result = GIN_MAYBE;

    for (int i = 0; i < nkeys; i++) {
        if (check[i] == GIN_FALSE)
            return GIN_FALSE;

        if (check[i] == GIN_TRUE) {

            char *queryFenStr = TextDatumGetCString(queryKeys[i]);
            char *gameFenStr = TextDatumGetCString(query);

            if (strcmp(queryFenStr, gameFenStr) == 0)
                result = GIN_TRUE;
        }
    }

    PG_RETURN_GIN_TERNARY_VALUE(result);
}
```

`has_board_fn_operator and fen_in_san_eq`

Both determine if a given FEN type matches any board state in a SAN type
Input: (FEN) a, (SAN) b.
Output: (Boolean) True if the result of the comparison between FEN string a and the SAN string from the indexed key (using `san_to_fen`) is less than 0; otherwise, False.



```
Datum has_board_fn_operator(PG_FUNCTION_ARGS)
{
    FEN *input_fen, *result_fen;
    SAN *san, *gameTruncated;

    int i;
    bool result;
    const char *fenConversionStrResult;

    if (PG_ARGISNULL(0) || PG_ARGISNULL(1))
        ereport(ERROR, (errmsg("has_board_fn_operator: One of the arguments is null\n")));

    result_fen = (FEN *)palloc(sizeof(FEN));
    input_fen = (FEN *) PG_GETARG_POINTER(1);
    san = (SAN *) PG_GETARG_CHESSGAME_P(0);

    i=0;
    result = false;

    while (true) {

        gameTruncated = truncate_san(san, i);

        if (gameTruncated == NULL)
            break;

        fenConversionStrResult = san_to_fen(gameTruncated);

        if (fenConversionStrResult == NULL)
            ereport(ERROR, (errmsg("has_board_fn_operator: No FEN result returned from mapping san to fen")));

        parseStr_ToFEN(fenConversionStrResult, result_fen);

        if (strcmp(result_fen->positions, input_fen->positions) == 0)
        {
            result = true;
            break;
        }

        i++;
    }

    PG_RETURN_BOOL(result);
}
```