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PostgreSQL Tuples

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❖ PostgreSQL Tuples

Definitions: `include/postgres.h`, `include/access/*tup*.h`

Functions: `backend/access/common/*tup*.c` e.g.

- `HeapTuple heap_form_tuple(desc,values[],isnull[])`
- `heap_deform_tuple(tuple,desc,values[],isnull[])`

PostgreSQL implements tuples via:

- a contiguous chunk of memory
- starting with a header giving e.g. #fields, nulls
- followed by data values (as a sequence of **`Datum`**)

❖ PostgreSQL Tuples (cont)

`HeapTupleData` contains information about a stored tuple

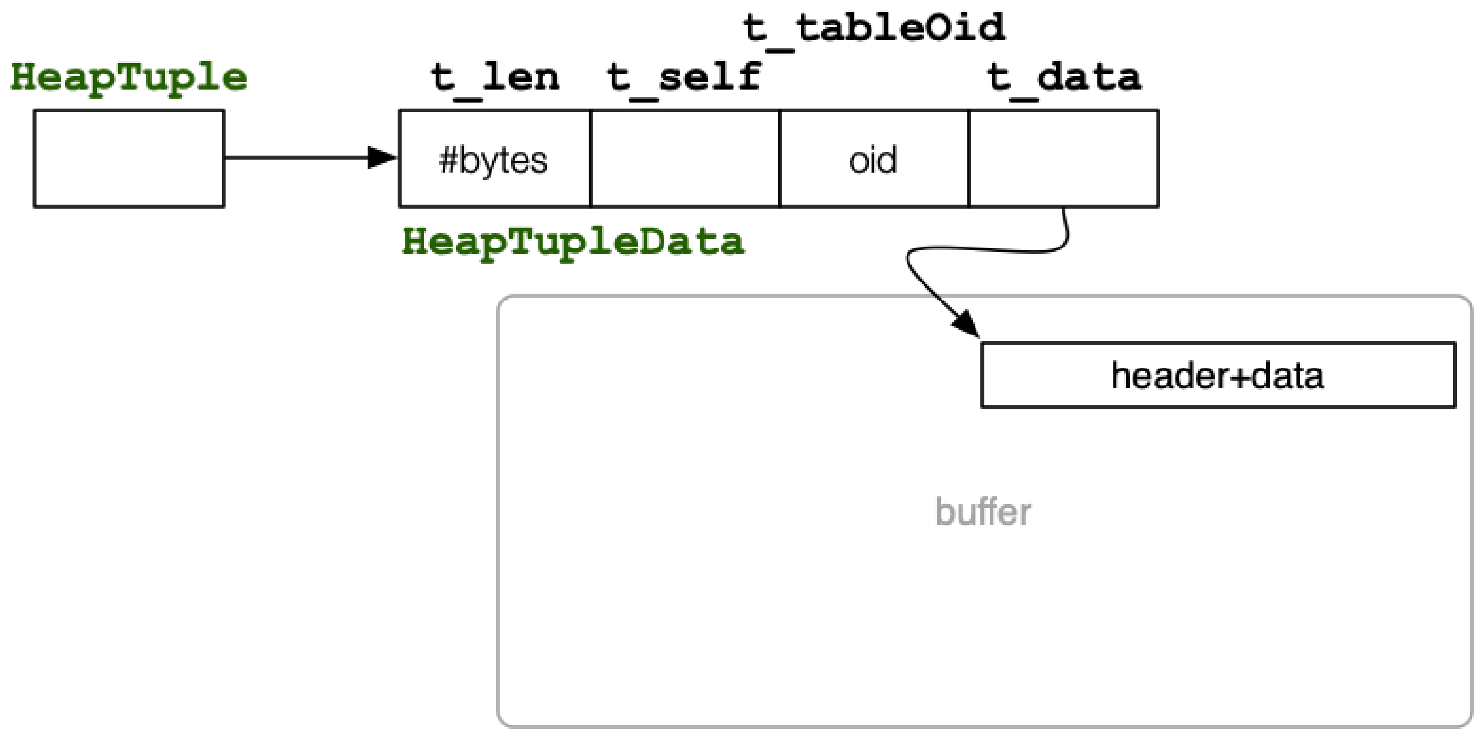
```
typedef HeapTupleData *HeapTuple;

typedef struct HeapTupleData
{
  uint32           t_len;   // length of *t_data
  ItemPointerData t_self;   // SelfItemPointer
  Oid          t_tableOid;  // table the tuple came from
  HeapTupleHeader t_data;   // -> tuple header and data
} HeapTupleData;
```

`HeapTupleHeader` is a pointer to a location in a buffer

❖ PostgreSQL Tuples (cont)

Structure of **`HeapTuple`**:



❖ PostgreSQL Tuples (cont)

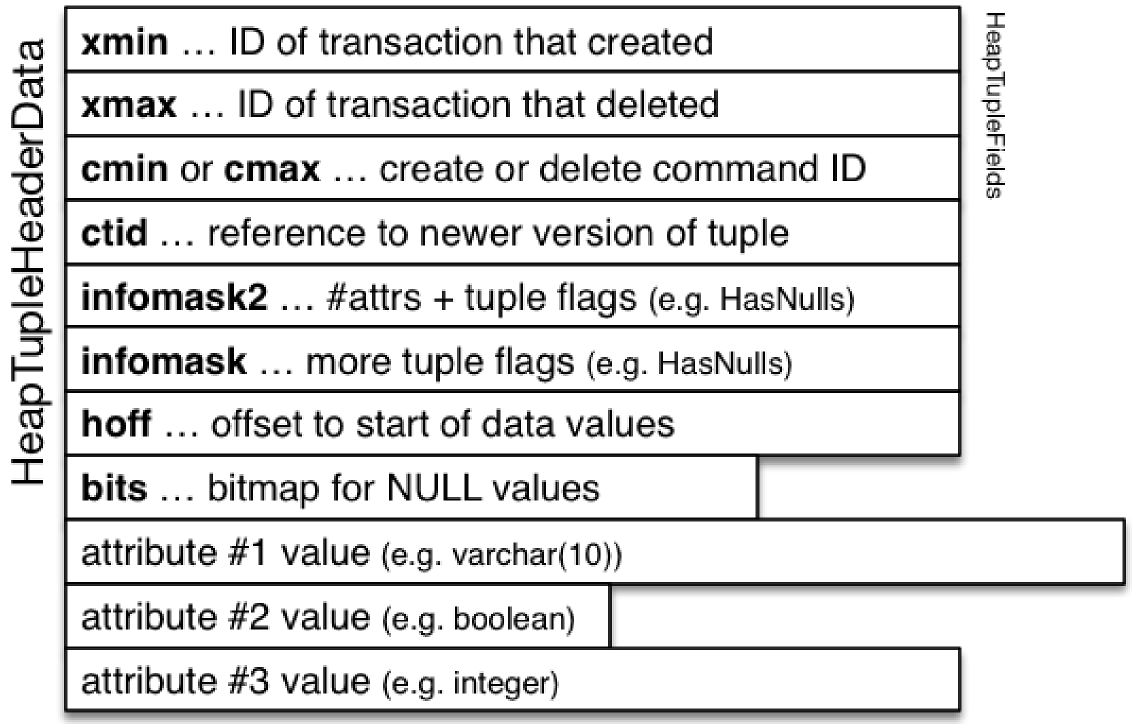
PostgreSQL stores each record as tuple header, followed by data:

```
typedef HeapTupleHeaderData *HeapTupleHeader;

typedef struct HeapTupleHeaderData // simplified
{
  HeapTupleFields t_heap;
  ItemPointerData t_ctid;       // TID of newer version
  uint16          t_infomask2;  // #attributes + flags
  uint16          t_infomask;   // flags e.g. has_null
  uint8           t_hoff;       // sizeof header incl. t_bits
  // above is fixed size (23 bytes) for all heap tuples
  bits8           t_bits[1];    // bitmap of NULLs, var.len.
  // OID goes here if HEAP_HASOID is set in t_infomask
  // actual data follows at end of struct
} HeapTupleHeaderData;
```

❖ PostgreSQL Tuples (cont)

Tuple structure:


HeapTupleHeaderData
HeapTupleFields
xmin … ID of transaction that created
xmax … ID of transaction that deleted
cmin or **cmax** … create or delete command ID
ctid … reference to newer version of tuple
infomask2 … #attrs + tuple flags (e.g. HasNulls)
infomask … more tuple flags (e.g. HasNulls)
hoff … offset to start of data values
bits … bitmap for NULL values
attribute #1 value (e.g. varchar(10))
attribute #2 value (e.g. boolean)
attribute #3 value (e.g. integer)

❖ PostgreSQL Tuples (cont)

Some of the bits in **`t_infomask`** ..

```
#define HEAP_HASNULL        0x0001
        /* has null attribute(s) */
#define HEAP_HASVARWIDTH    0x0002
        /* has variable-width attribute(s) */
#define HEAP_HASEXTERNAL    0x0004
        /* has external stored attribute(s) */
#define HEAP_HASOID_OLD     0x0008
        /* has an object-id field */
```

Location of **`NULL`**s is stored in **`t_bits[]`** array

❖ PostgreSQL Tuples (cont)

Tuple-related data types: (cont)

```
typedef struct HeapTupleFields  // simplified
{
  TransactionId t_xmin;   // inserting xact ID
  TransactionId t_xmax;   // deleting or locking xact ID
  union {
    CommandId   t_cid;    // inserting or deleting command ID
    TransactionId t_xvac;// old-style VACUUM FULL xact ID
  } t_field3;
} HeapTupleFields;
```

Note that not all system fields from stored tuple appear

- **`oid`** is stored after the tuple header, if used
- both **`xmin`**/**`xmax`** are stored, but only one of **`cmin`**/**`cmax`**

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❖ PostgreSQL Tuples (cont)

Tuple-related data types: (cont)

```
// TupleDesc: schema-related information for HeapTuples

typedef struct tupleDesc
{
  int          natts;        // # attributes in tuple
  Oid          tdtypeid;     // composite type ID for tuple type
  int32        tdtypmod;     // typmod for tuple type
  bool         tdhasoid;     // does tuple have oid attribute?
  int          tdrefcount;   // reference count (-1 if not counting)
  TupleConstr *constr;       // constraints, or NULL if none
  FormData_pg_attribute attrs[];
  // attrs[N] is a pointer to description of attribute N+1
} *TupleDesc;
```

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❖ PostgreSQL Tuples (cont)

Tuple-related data types: (cont)

```
// FormData_pg_attribute:
// schema-related information for one attribute

typedef struct FormData_pg_attribute
{
  Oid       attrelid;     // OID of reln containing attr
  NameData  attname;      // name of attribute
  Oid       atttypid;     // OID of attribute's data type
  int16     attlen;       // attribute length
  int32     attndims;     // # dimensions if array type
  bool      attnotnull;   // can attribute have NULL value
  .....                   // and many other fields
} FormData_pg_attribute;
```

For details, see **`include/catalog/pg_attribute.h`**

❖ PostgreSQL Attribute Values

Attribute values in PostgreSQL tuples are packaged as **`Datum`**s

```
// representation of a data value
typedef uintptr_t Datum;
```

The actual data value:

- may be stored in the **`Datum`** (e.g. **`int`**)
- may have a header with length (for varlen attributes)
- may be stored in a TOAST file (if large value)

❖ PostgreSQL Attribute Values (cont)

Attribute values can be extracted as **Datum** from **HeapTuple**s

```
Datum heap_getattr(
          HeapTuple tup,        // tuple (in memory)
          int attnum,           // which attribute
          TupleDesc tupDesc,    // field descriptors
          bool *isnull          // flag to record NULL
)
```

isnull is set to true if value of field is **NULL**

attnum can be negative ... to access system attributes (e.g. OID)

For details, see **include/access/htup_details.h**

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❖ PostgreSQL Attribute Values (cont)

Values of **`Datum`** objects can be manipulated via e.g.

```
// DatumGetBool:
//   Returns boolean value of a Datum.

#define DatumGetBool(X) ((bool) ((X) != 0))

// BoolGetDatum:
//   Returns Datum representation for a boolean.

#define BoolGetDatum(X) ((Datum) ((X) ? 1 : 0))
```

For details, see **`include/postgres.h`**

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