Backwards-Compatible Array Bounds Checking for C with Very Low Overhead

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C bounds checking

- fat pointers
  - not compatible for unchecked code
- separate metadata
  - pointer-to-metadata map
  - careful engineering allows compatibility

Automatic Pool Allocation

- merge all target objects of one pointer to a pool
- „pools will be type homogeneous with a known type“
- pools convey type information for pointers

Automatic Pool Allocation

Chris Lattner and Vikram Adve

Presented by William Lovas

Motivation

- Data locality is important!
- Compilers are good with arrays…
- … but bad with pointer-based data structures

Motivation

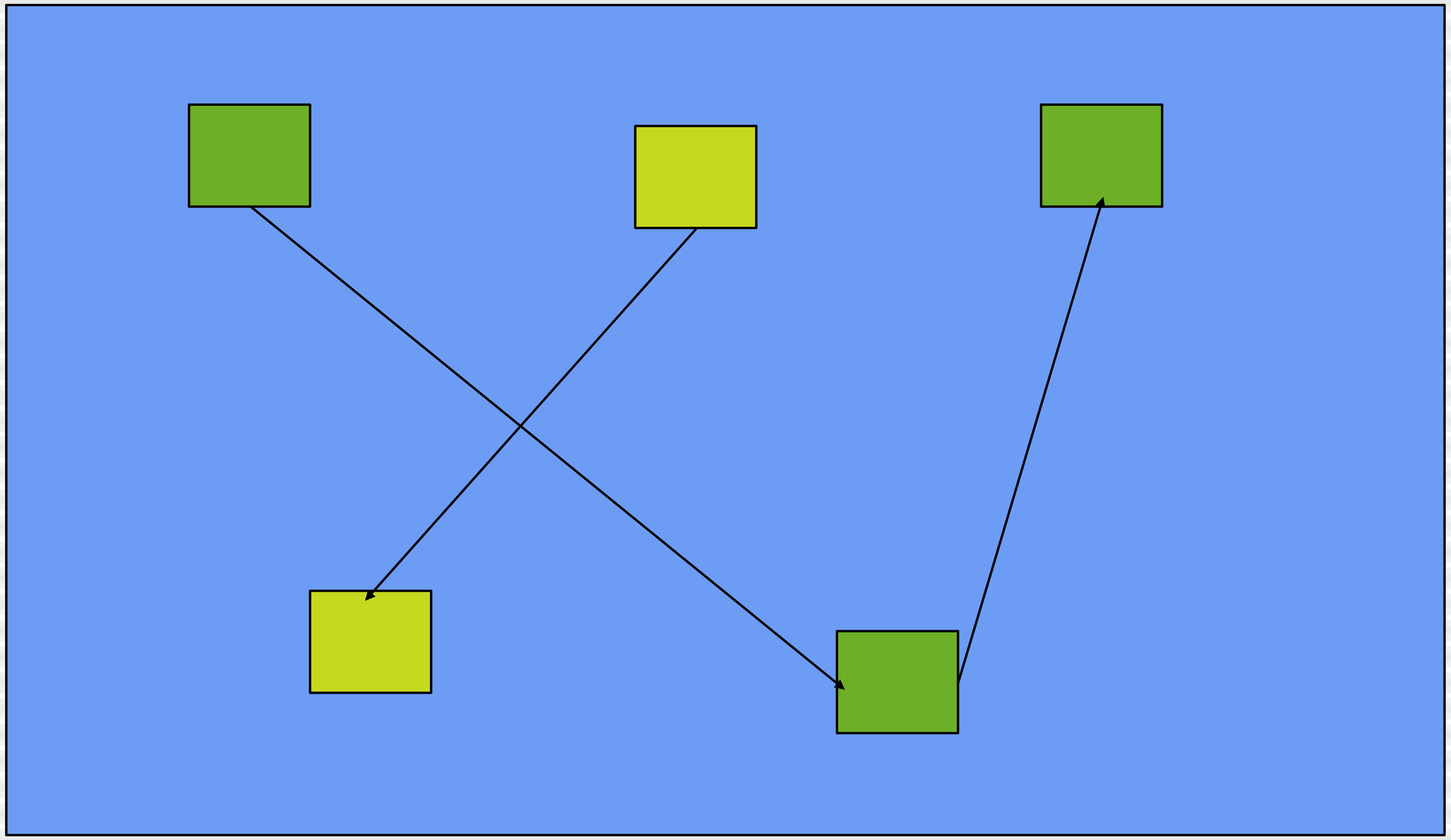
- Existing techniques focus on individual references or data elements
- Big idea: analyze how programs use ***entire data structures!***

Pool Allocation

- Allocate disjoint data structures in disjoint portions of the heap (pools)
- … automatically, via static program transformation!

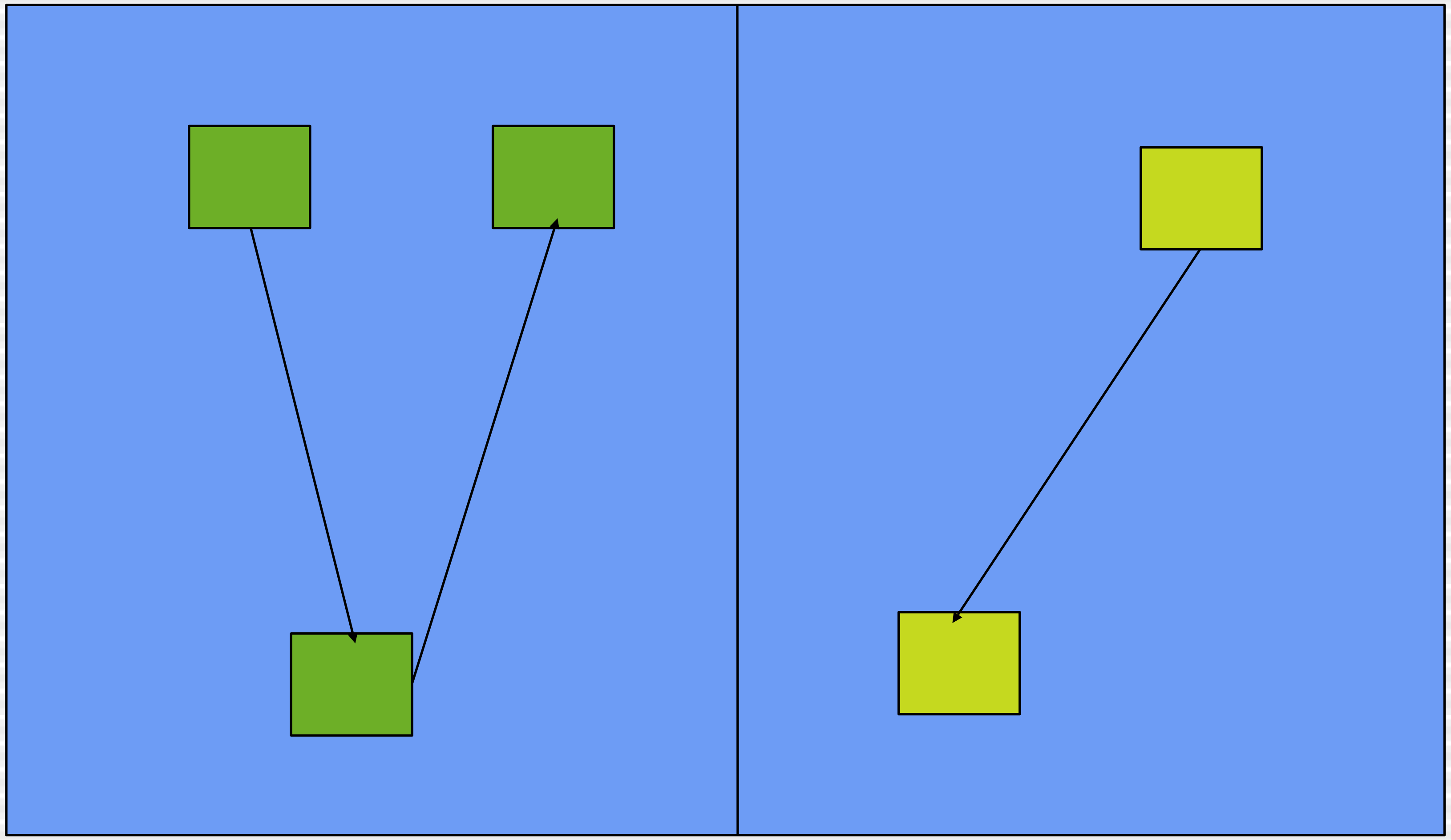
Pool Allocation

- Transform:



Pool Allocation

- Into:



Approach

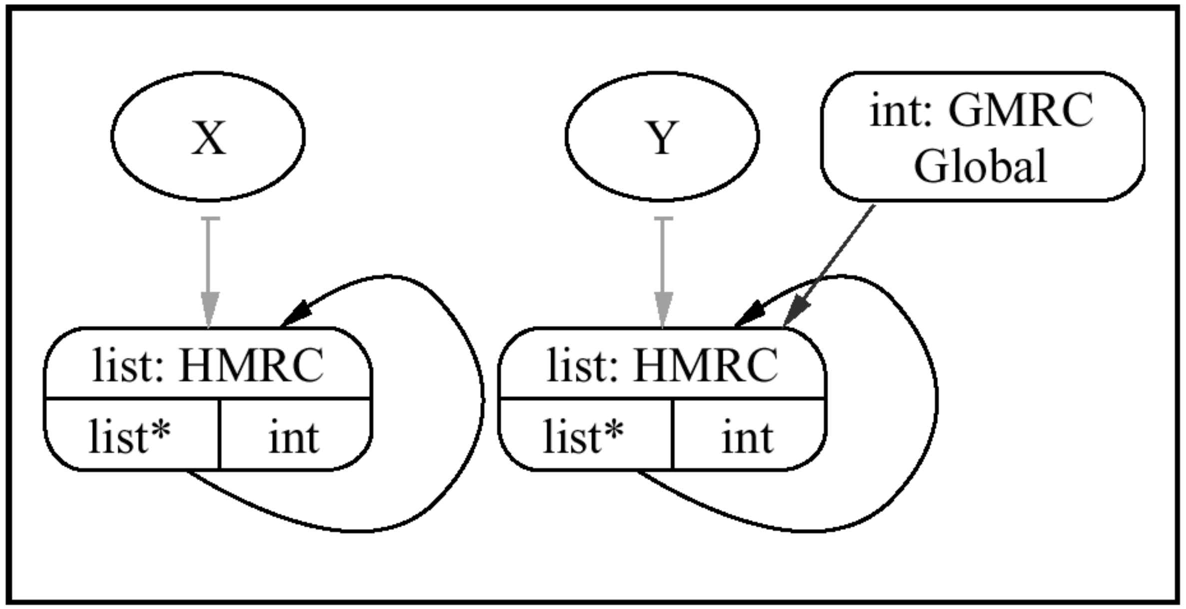
- Create a *data structure graph* for each function *F*
  - A “points-to” graph with some extra info
- DS graph records, for each object:
  - Type of the object
  - Whether it’s heap-allocated
  - Whether it escapes *F*

Approach

- Use DS graph to assign a pool to each object
- Use assignment to rewrite program:
  - Calls to *malloc/free* become calls to *pool_alloc/ pool_free*
  - Creates local pools for non-escaping objects
  - Adds pool arguments for escaping objects

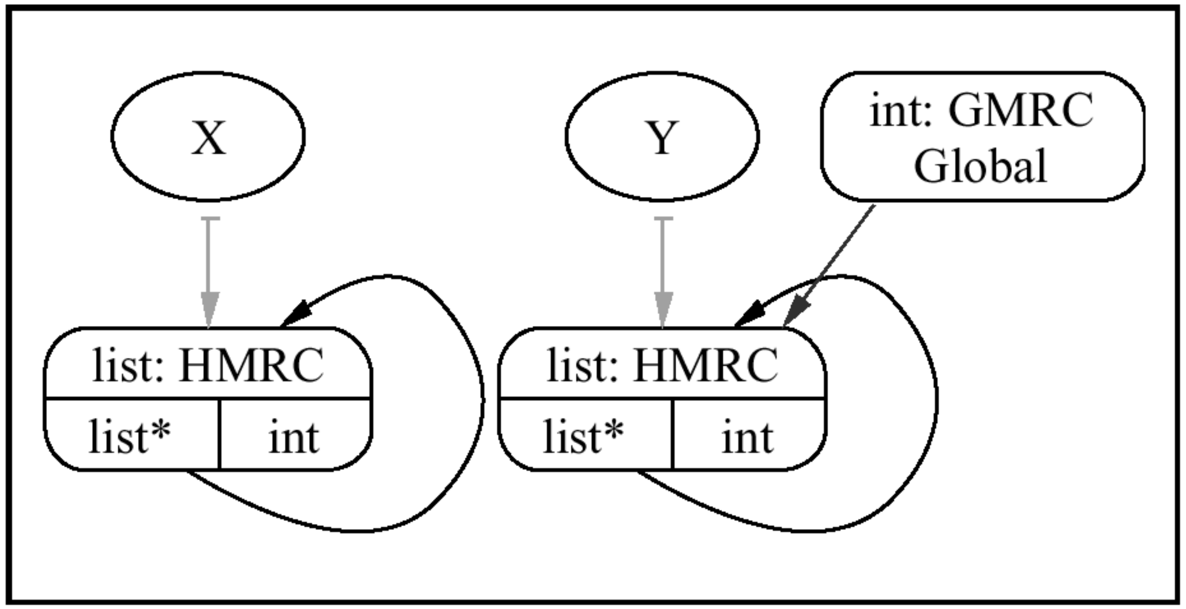
Example [Lattner]

```
list *makeList(int Num) {
   list *New = malloc(sizeof(list));
   New->Next = Num ? makeList(Num-1)      : 0;
   New->Data = Num; return New;
}

void twoLists(               ) {


   list *X = makeList(10);
   list *Y = makeList(100);
   GL = Y;
   processList(X);
   processList(Y);
   freeList(X);
   freeList(Y);

}
```



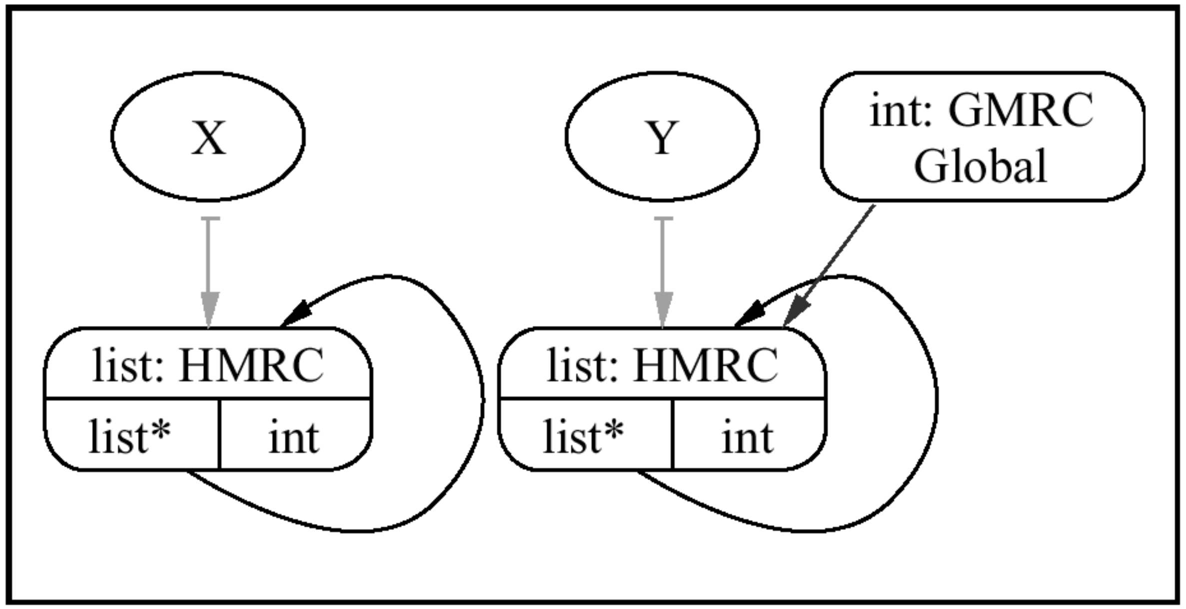
Example [Lattner]

```
list *makeList(int Num, Pool *P) {
   list *New = pool_alloc(P, sizeof(list));
   New->Next = Num ? makeList(Num-1, P) : 0;
   New->Data = Num; return New;
}

void twoLists(             ) {


   list *X = makeList(10);
   list *Y = makeList(100);
   GL = Y;
   processList(X);
   processList(Y);
   freeList(X);
   freeList(Y);

}
```



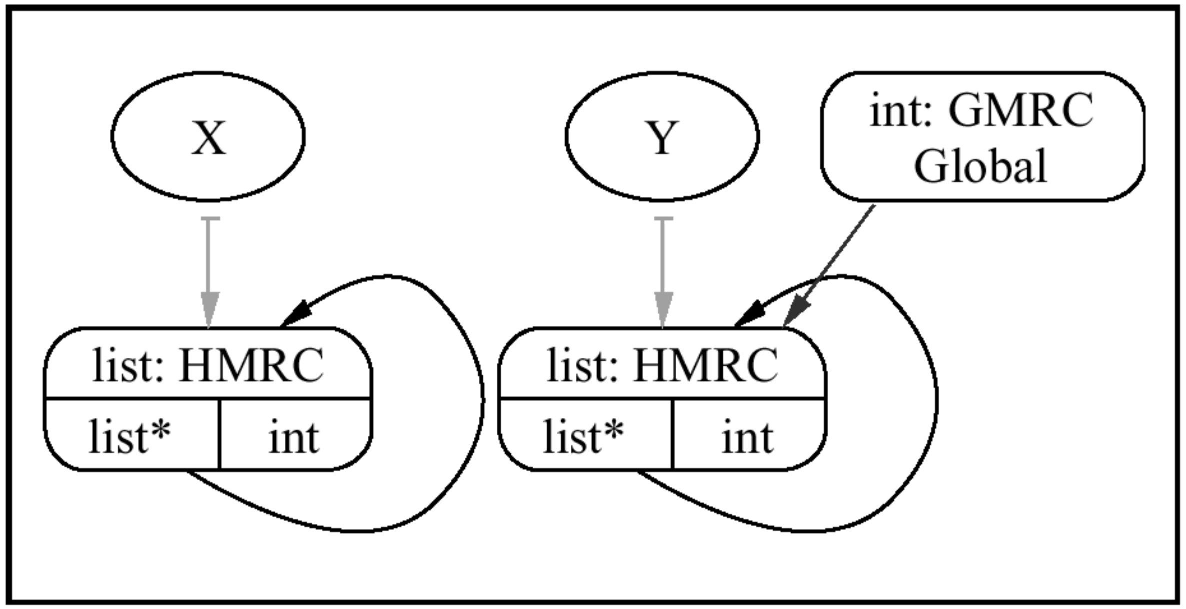
Example [Lattner]

```
list *makeList(int Num, Pool *P) {
  list *New = pool_alloc(P, sizeof(list));
  New->Next = Num ? makeList(Num-1, P) : 0;
  New->Data = Num; return New;
}

void twoLists(           ) {
  Pool P1;
  pool_init(&P1);
  list *X = makeList(10, &P1);
  list *Y = makeList(100);
  GL = Y;
  processList(X);
  processList(Y);
  freeList(X, &P1);
  freeList(Y);
  pool_destroy(&P1);
}
```



Example [Lattner]

```
list *makeList(int Num, Pool *P) {
   list *New = pool_alloc(P, sizeof(list));
   New->Next = Num ? makeList(Num-1, P) : 0;
   New->Data = Num; return New;
}

void twoLists( Pool *P2 ) {
   Pool P1;
   pool_init(&P1);
   list *X = makeList(10, &P1);
   list *Y = makeList(100, P2);
   GL = Y;
   processList(X);
   processList(Y);
   freeList(X, &P1);
   freeList(Y, P2);
   pool_destroy(&P1);
}
```



Difficulties

- Function pointers
  - Two functions with *different properties* might be called (indirectly) at the *same site*
- Solution:
  - Partition functions into equivalence classes
  - Merge DS graphs

Difficulties

- Global pools
  - Pool arguments for heap-allocated globals must be added to *every function that touches the globals*
  - Can be *thousands of arguments* in practice
- Solution:
  - Use global variables for global pools
  - Pool arguments grow with original arguments

Results

- Small additional compile time
  - <= 1.25 seconds in all experiments
  - <= 3% of total compile time
- Low overhead
  - <= 5% in most experiments
- Improved performance
  - 5% to 20% in most experiments
  - 2x and 10x in a few examples

Results

- Limited discussion of corner cases

- Automatic pool allocation could *decrease* performance
  - Decrease locality for certain access patterns
  - Small pools on nearly-empty pages

  - Some techniques help address these issues

Conclusions

- Simple yet sophisticated data structure analysis, for data locality
- Experimentally validated
- Not obviously universally applicable

Engineering

- use type-information provided by pooling to speed up pointer metadata search
- heavier verification for pointer arithmetics
- lightweight verification for pointer use
- track out-of-bounds pointers

Questions

- What errors cannot be detected?
- How „safe“ are we compared to Java / OCaml / …?
- Are the C-library wrappers for API-checking cheating?
- Usability of the approach?