Simple Inter-Procedural Register Allocation in Compiler for Network Processor

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Register Allocation

- **What is the register allocation?**
  - Find assignment of variables and temporaries to registers.
- **Why we need register allocation?**
  - Registers are fast and limited in number.
  - Good utilization of registers improves performance.
  - In some machines (RISC) ALU operations only on registers.
- **Register Allocation is divided into three levels (Usually):**
  - Basic Block local, Basic Block global, and inter-procedural.
- **Basic Block local**
  - All registers assumed to be not valid after end of BB.
  - Used with the Basic Block global register allocation.

Register Allocation Cont.

- **Basic Block global (intra-procedural)**
  - Register allocation inside procedures.
  - Equivalent to Graph coloring problem - registers are colors, live ranges are nodes; arc when live ranges intersect.
  - Caller or Callee Save/Restore is needed.
  - Spilling is optimized in the procedure level.
  - Library function handling is simple.
  - Good for general applications.
- **Inter-Procedural register allocation:**
  - "Whole Program" scope - Requires call-graph and global program view.
  - Saves and restores of registers only when needed.
  - Profiling to optimize spilling could be useful.
  - Library functions is an issue
  - Good in special cases - Embedded systems is one of these cases.

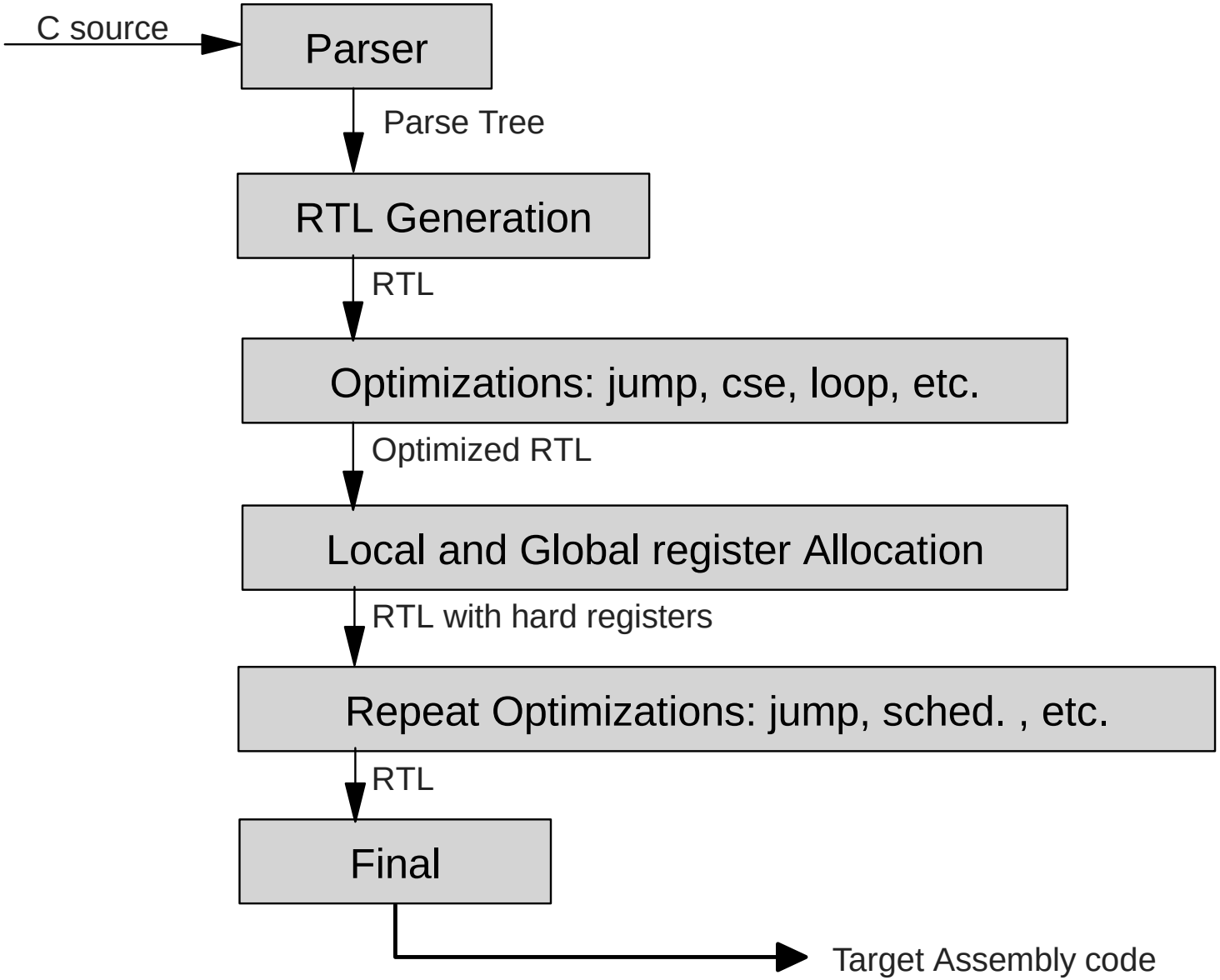
Why Use Inter-Procedural Register allocation in PowerNP C Compiler?

- Wire speed applications - Every single instruction reduction is important.
- PowerNP procedures are small (hundred of lines).
- A single procedure probably does not use more than half of the registers. (32 general purpose registers).
- The whole program is known at compile time (even library functions); hence register requirements are known.
- Incremental building is not crucial.
- Profiling is possible and maybe efficient.

C Compilation Process in GCC

- **Process each procedure separately**
  - Pass the procedure through the whole compilation process, then go to the next procedure in the input.
- **Parsing pass**
  - Build a syntax tree of the procedure in the input.
- **RTL generation pass**
  - RTL (Register Transfer Language) is used throughout the compilation process.
  - Translate the syntax tree of a procedure into a list of RTL instructions.
- **Optimization and Register allocation passes**
  - Performed on the RTL representation of the function.
  - Local register allocation (in the level of basic blocks).
  - Global register allocation (across basic block boundaries and within function boundaries).
- **Final pass**
  - Assembly generation- translate the RTL representation to assembly.

Compilation Process Diagram



Register Allocation in GCC

- **Performed on the RTL representation.**
- **In RTL generation pass, pseudo registers are used.**
- **Live ranges according to the SET/USE/CLOBBER in the RTL instructions.**
  - Example RTL instruction:

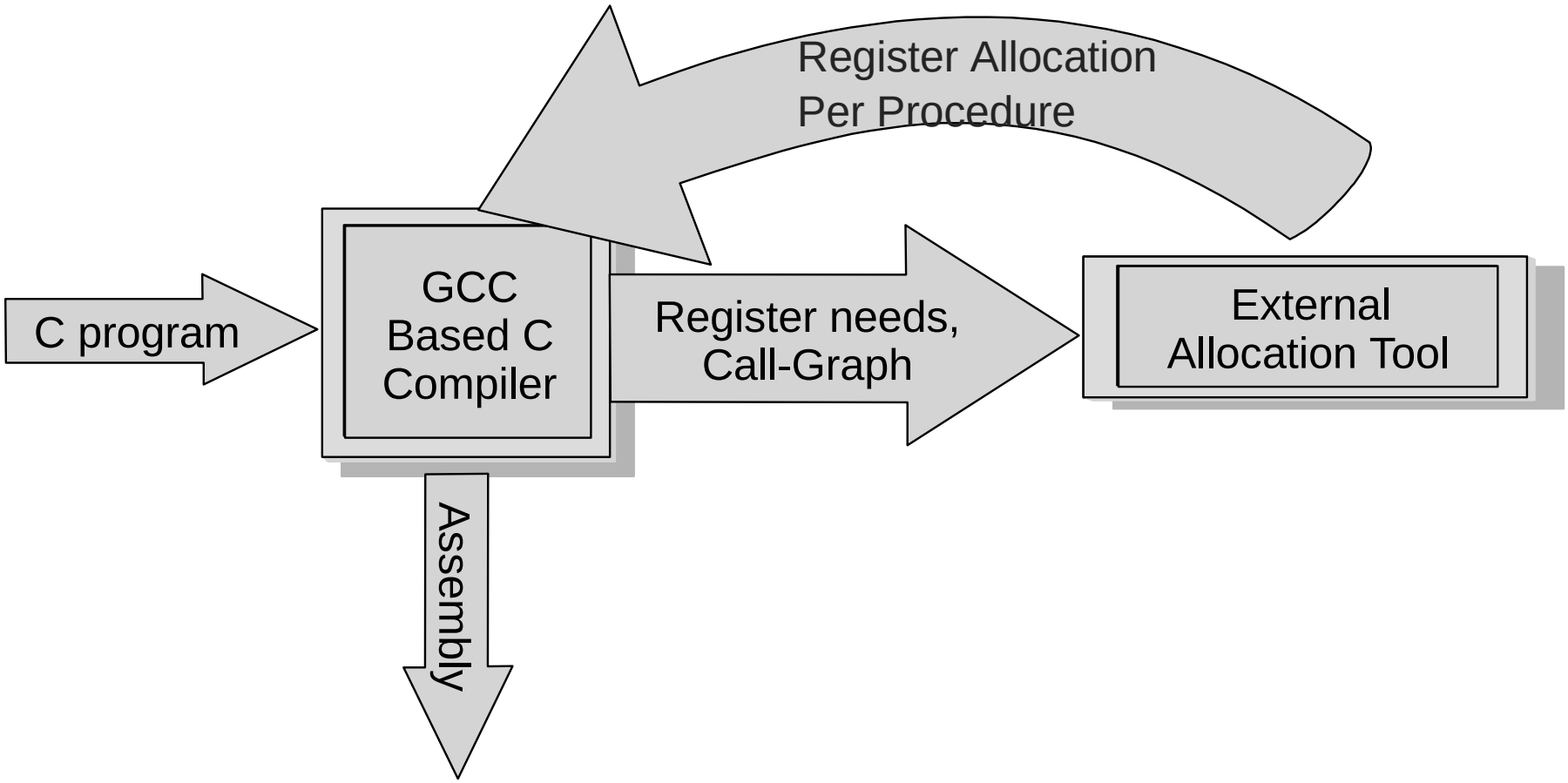
    (insn 12 10 14 (set (reg/v:HI 307) (and:HI (reg/v:HI 307) (const_int 10))))
- **CALL instructions are special.**
  - CALL-USED registers macro - defined per compiler build.
  - CLOBBER/SET/USE in the CALL RTL instruction.
  - Example:

    (call_insn 21 19 23 ([(call (symbol_ref:HI ("fAnd1")))
    (clobber (reg:HI r8)) (clobber (reg:HI r31))]) (expr_list (use (reg:HI r8))))
- **Local and GLOBAL register allocation:**
  - Is to assign pseudo registers to hard registers (real machine registers).
  - Live/Dead analysis using the SET/USE/CLOBBER in the RTL instructions.

Implementing Inter-Procedural Register Allocation in GCC

- **Simplification of the problem:**
  - Find a set of registers per procedure.
  - Colliding procedures must have different sets.
  - If a procedure needs more registers:
    - Use registers of the successors
    - Save/Restore registers around calls if needed.
- **Missing in GCC:**
  - Finding the registers per procedure.
  - Save/Restore callee registers around calls.
- **Solution:**
  - Use External Allocation Tool
    - Input: Register needs for each procedure, Call graph.
    - Output: Set of registers per procedure.
  - CLOBBER in the CALL RTL instruction for each register used in the callee and its successors.
  - Assumptions:
    - No function pointers - All the calls are known at compile time.
    - No recursion - Recursion is possible but not efficient.

Compilation Process with External Allocation Tool



Compilation - Allocation Loop

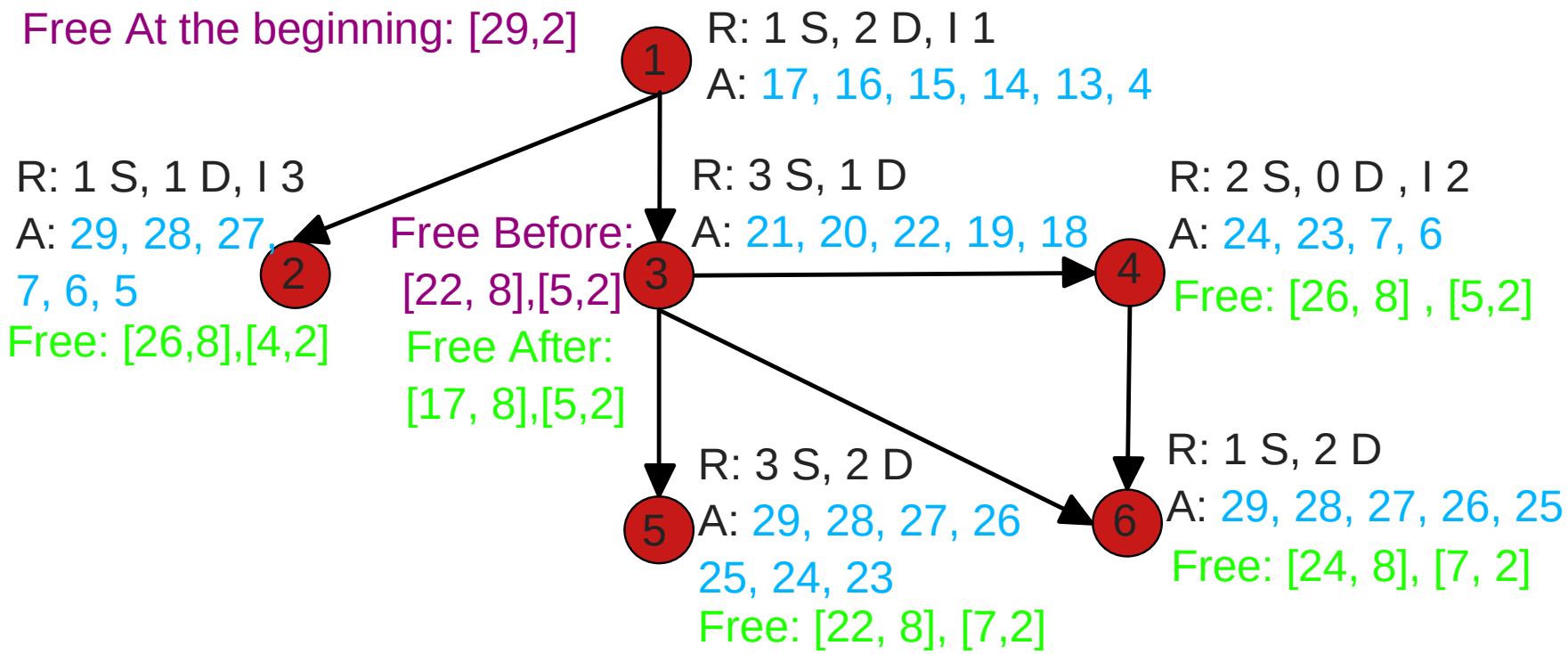
- **GCC Starts :**
  - Assume all registers available.
  - Generate requirements for each procedure.
- **Allocation routine:**
  - Set of registers per-procedure feedback to GCC.
- **GCC runs Again:**
  - Register Allocation is according to the feedback.
  - May spill registers.
  - Requirements may change - allocation should be repeated.
- **End the Loop:**
  - When the requirements doesn't change.
  - Or reached a maximum number of iterations (to avoid endless loop).
- **Is the compilation-allocation loop required?**
  - No, the register allocation could be applied on the generated assembly.
  - But, code correctness must be insured - re-implement part of the compiler.

Inter-Procedural Allocation Tool Algorithm

- **PowerNP general purpose registers:**
  - 32 16 bit registers (4 of them has a special use).
  - Accessed as a singles (r3 for example), or doubles (w2, r3 and r2).
  - Index registers (registers 0 to 7).
- **Input**
  - Procedure information:
    - Amount of registers needed from each register type.
    - The list of calls to other procedures.
- **Output:**
  - A set of registers per procedure.
- **Data Structure:**
  - Graph (call graph): A node represents a procedure, a directed arc represents a call.
  - Node has:
    - Register requirements (double, single, and address).
    - free registers bitmap.
    - Incoming and outgoing arcs.
    - Allocated registers.

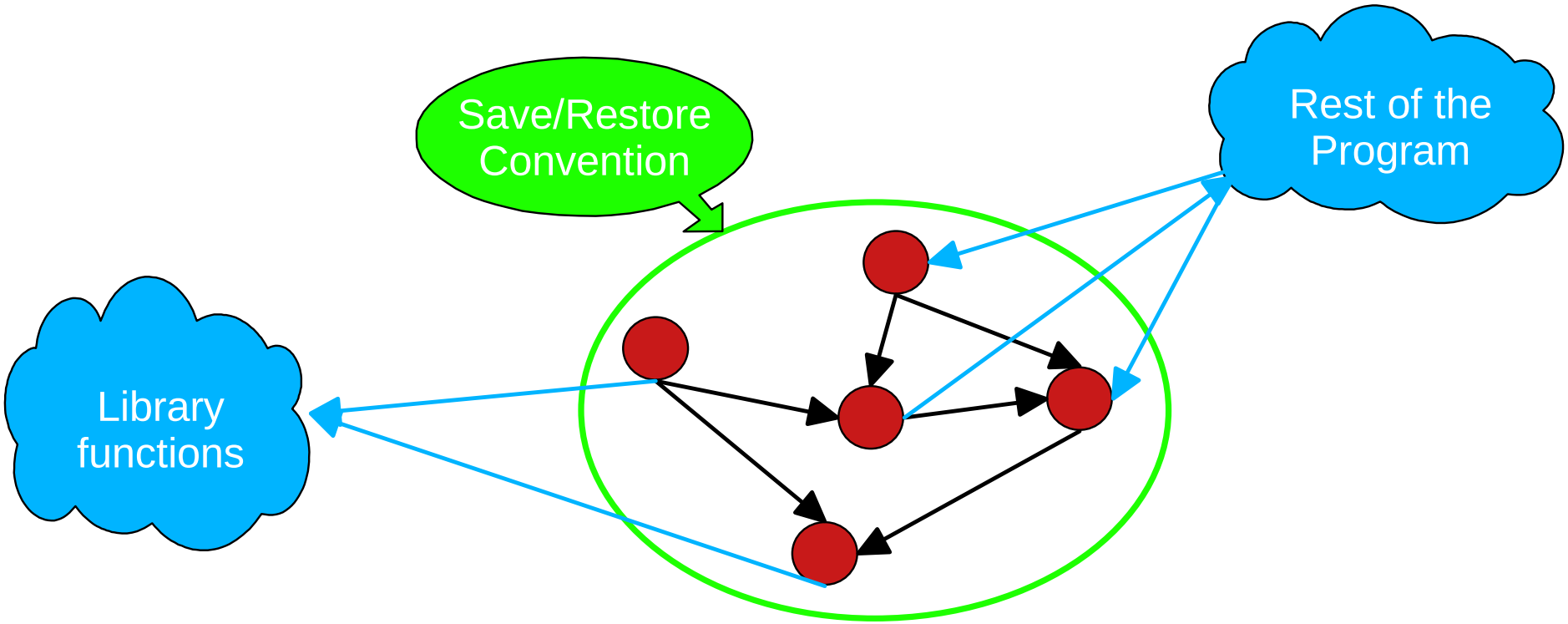
Inter-Procedural register Allocation Algorithm Cont.

- **Algorithm**
  - Traverse the nodes in DFS reverse order (leafs first).
  - In each node do :
    - free registers bitmap = Intersection of free registers bitmaps of its successors.
    - Satisfy register requirements: Allocate Index first, then double and single at last.
    - Update the free registers bitmap and the allocation list.
- **Example:**



Inter-Procedural Allocation for General Application

- **This method could be used in general purpose applications.**
- **Only On the part of the Call-Graph which is:**
  - Critical for performance.
  - Doesn't contain cycles.
  - All the calls are known at compile time.



Summary

- Results show efficient code; inter-procedural register allocation is one reason for that.
- Profiling could be used to minimize spilling overhead.
- Recursion could be allowed theoretically, practically it requires dynamic memory handling - This is not the trend in embedded systems.

END

- End