XFOCUS TEAM
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Static Detection of Vulnerability by Data Flow Analysis

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X'CON 2004

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- Review
- System Architecture
- Intermedia Representation Language
- Data Flow Analysis
- The End

Review

- The early automated scripts, tools
- The Advantages of these tools
- Existed problems
- Our deficiency
- What are the vendors doing?

The early scripts, tools

- Basic ideas:
  - Pattern matching;
  - Limited back trace.
- Examples
  - Tools scanning source codes, sucn as FlowFinder, ITS4;
  - Tools scanning binary objects, series of idc scripts.

The Advantages of these tools

- Easy to develop;
- Run faster;
- Lower resource consuming;

The existed problems

- Cpu dependence;
- Too much false negatives, for the reason of the complexity of the problems coming from the real world;
- false positives! Our passions are flooded in the valueless points;
- Can not understand the program's semantics, and only analysis the intra-procedure part.

Our deficiency

- Pure experimentalism!
- lack of theory's support,don't know how to do it better.
- The period of the analysis is too long, and we need more automated tools.
- The tools need understand the programs.

What are the vendors doing?

- Microsoft's SLAM projects
  - 1999, 60M $,purchase intrinsa's prefix to control win2k's bugs.
  - Developes SLAM projects, detect bugs in drivers.
  - Theory:
    - Program Analysis, Model Checking, Automated Deduction
- IBM BEAM
  - Breviate for Bugs Errors And Mistakes
  - Theory:
    - Restrict data flow analysis to path that are executable.

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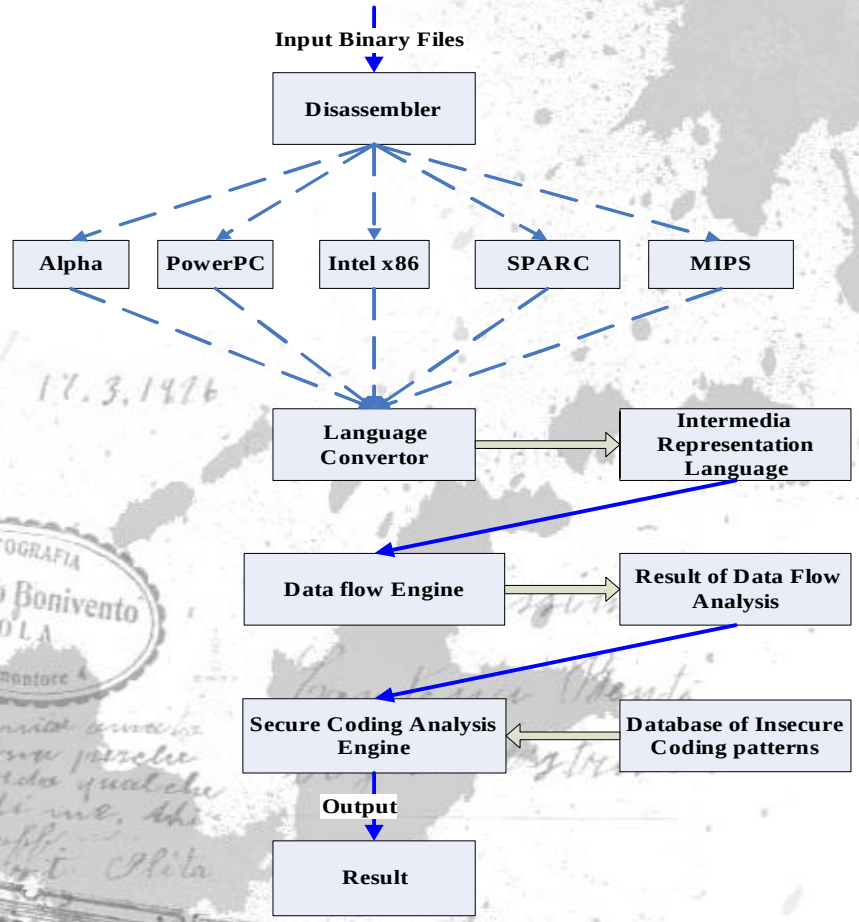
System Architecture



Intermedia Representation Language

- How to design?
- The form of intermedia Representation Language
- Our designing
- Existed problems

How to design?

- Steven S. Muchnick, Intermediate-language design is largely an art, not a science。
- Refer to other's fruits
  - Halvar Flake's MetaCPU

The form of the existed IR

- Existed Intermedia Representation
  - Polish prefix, quadruple, triple
- Quadruple is three address representation.The form is:
  - (op, arg1, arg2, result)
- When op has one or zero arg:
  - (op, arg1, ---, result) or (op, ---, ---, result)
- Triple is another form of quadruple, for reduce the temporary variables.

Our design

- Refer to the Halvar Flake's design
  - Risc-like
  - Sparc-like
  - No limitation of the num of the registers
    - 256 global regs, %g00-%gFF
    - 256 temporary regs,%t00-%tFF
    - 256 I/O regs，%i00-%iFF/%o00-%oFF
    - 256 flag regs，%f00-%fFF
    - PC，SP，FP

Our design

- Explicit accessing memory instructions
  - Mem as source address
    - mov reg, mem
    - ldm mem, ---, reg
  - Mem as the destination address
    - mov mem, reg
    - stm reg, ---, mem
- Explicit loop copy instructions
  - rep movsd
    - cmp gXX, 0
    - br_nz XXXXXXXX
    - dec gXX, 000004, gXX
    - ldm/stm
    - loop XXXXXXXX

Existed problems

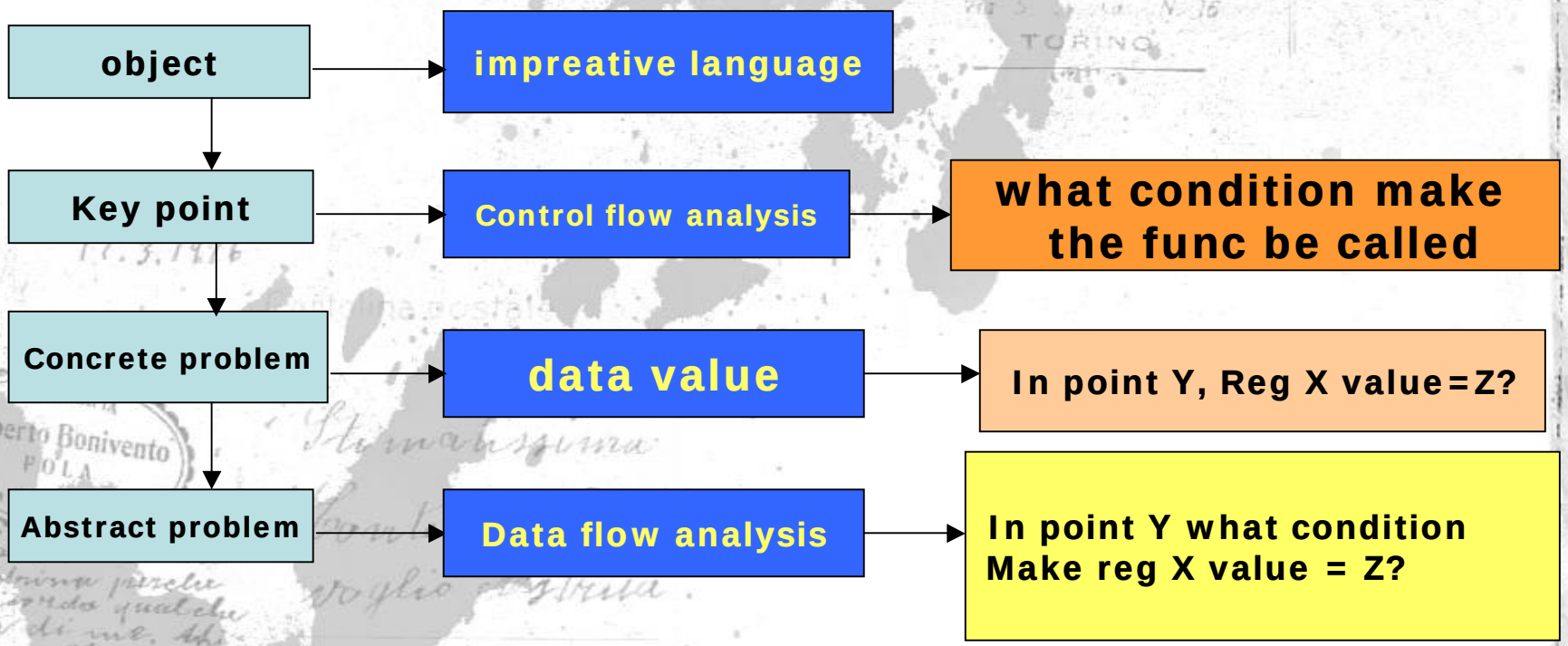
- Theory：
  - Can not prove the correctness of the translation;
  - Context-free grammar recognization **à** Context-sensitive grammar recognization.
- Practice：
  - Compiler optimization, need to be recognized.
  - The different optimization of different compilers will be translation's trouble maker!
  - For example, mov replace push, we must translate mov [esp+offset] to the proper output reg。

Before：	**push edx** **Push ecx** **call function** **add esp, 8**
After：	**sub esp, 8** **mov [esp+0], ecx** **mov [esp+4], eax** **call function**

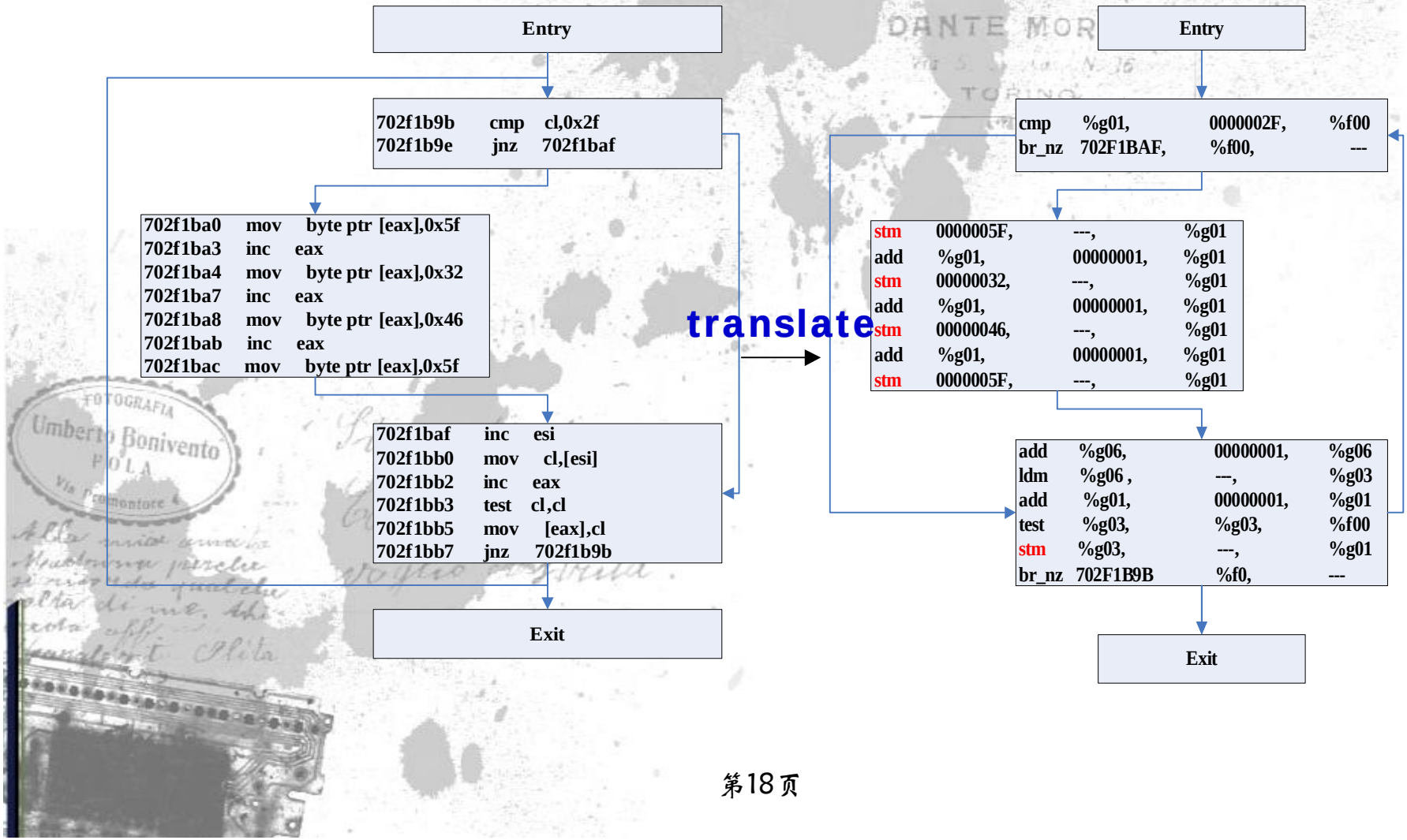
Data flow analysis

- why use data flow analysis?
- IE Object Type Property overflow analysis
- Basic block analysis
- Loop detection
- The demand for data flow analysis

Why we need data flow analysis?



IL Object Type Property overlow analysis



The principles of judgement

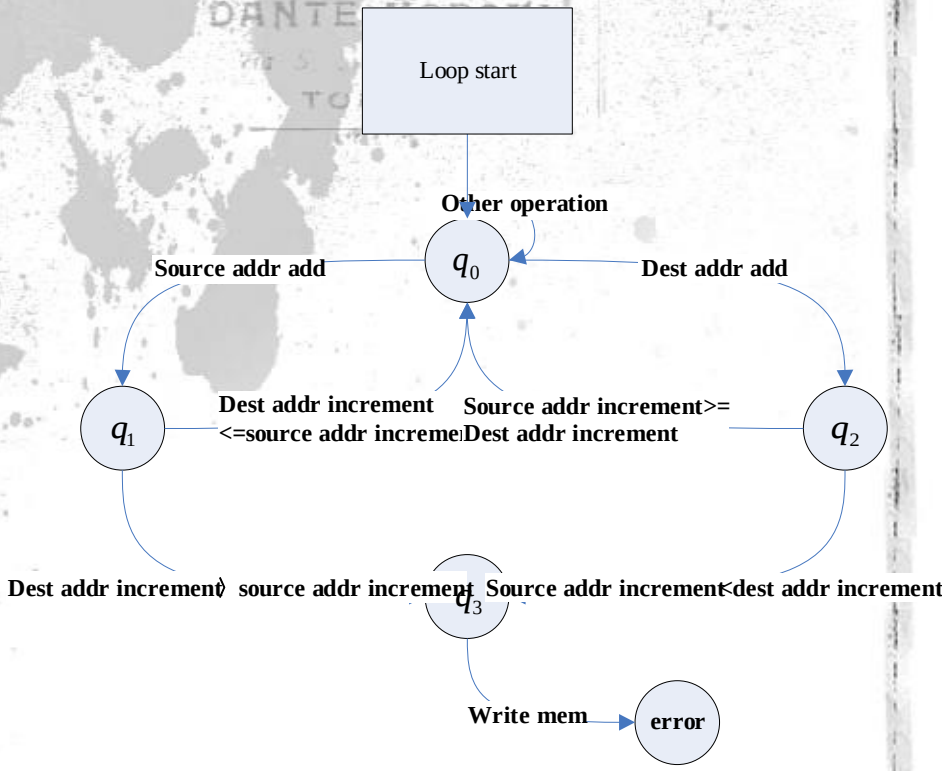
- If no stm in loops, not interested!
- If each time write the same position, not interested!
- If write a fixed number of bytes, not interested!

- This examples is very suspicious!

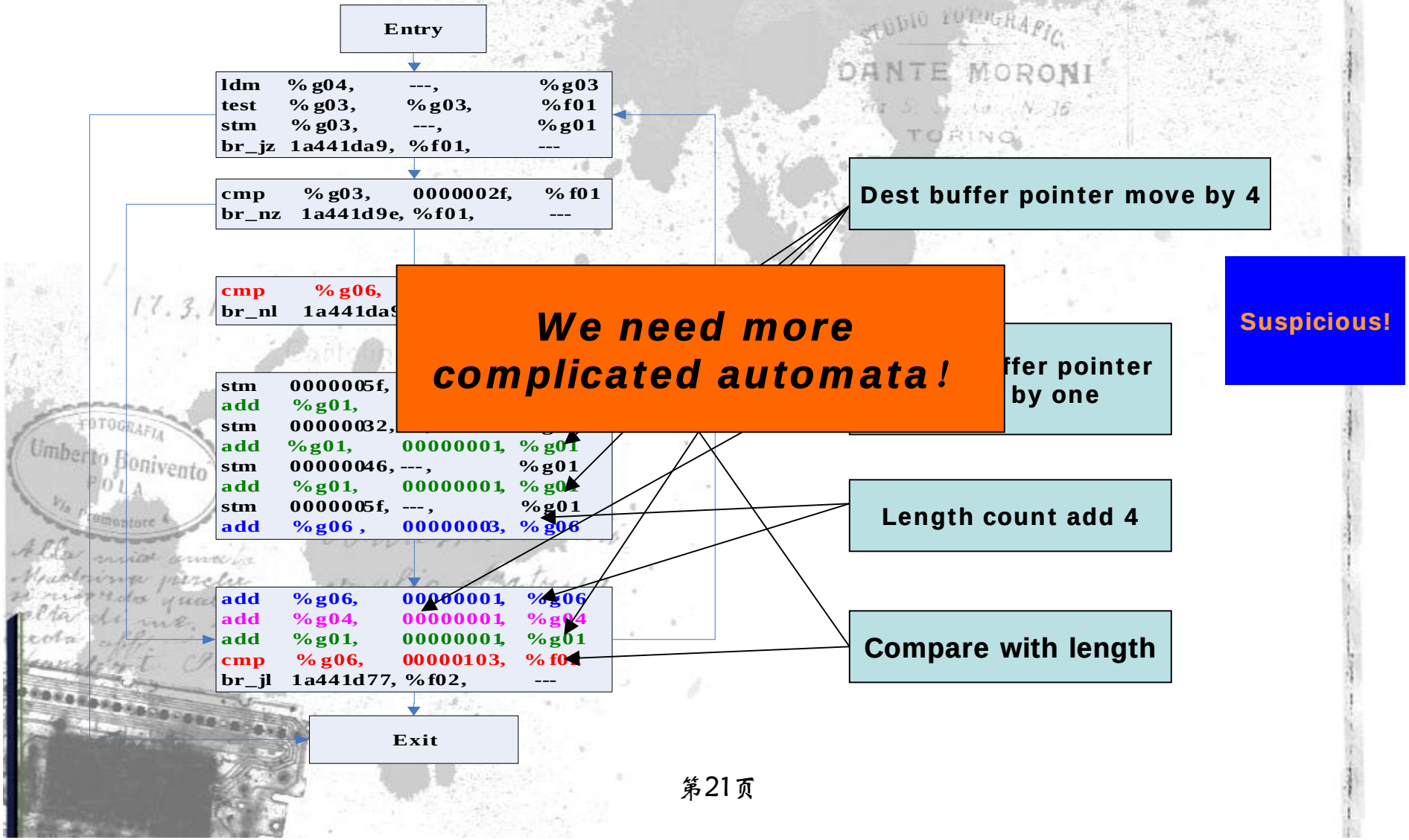
- We will use simplified automata to solve this sort of problems.

Push down Automata

- PDA is defined to be a sextuple machine
- Initial states:q0
- Final states:q0， error
- The execution can be described as the set of transition relation.
- Design more complicated automata
  - State transition for length comparison.
  - State transition for writing mem at a non-fixed point.



Analysis of the IE patch



If interested, more advanced topics

- Why not FSA
  - FSA is equal to type 3 grammar, but regular grammar can not describe the problem.
  - We need push symbols into stack!
- Why not Turing Machine
  - TM equal to type 0 grammar,too strong.
  - PDA equal to type 2 grammar, context-free grammar, enough!
- PDA classification
  - Terminates with final state (this example uses);
  - Terminates with empty stack.
  - Equivalence of both.

Basic Block

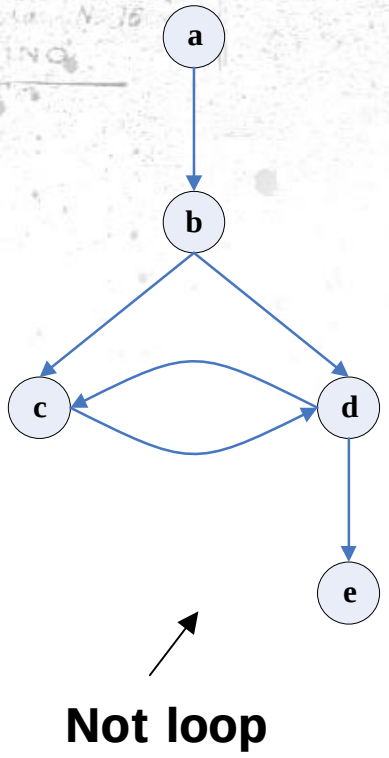
- Informally，A straight-line sequence of code that can be entered only at the beginning and exited only at the end
- The first instruction in a basic block may be
  - The entry point of the routine,
  - A target of a branch, or
  - An instruction immediately following a branch or a return.

The determination algorithm of basic blocks

- Determine the entry of each basic block.
- Through each entry, determine its including instruction.or when reaching the exit, all the instruction belong to the corresponding block.
- After the two steps, if one instruction is not included in any block, it is unreachable, we can delete it.

Loop detection

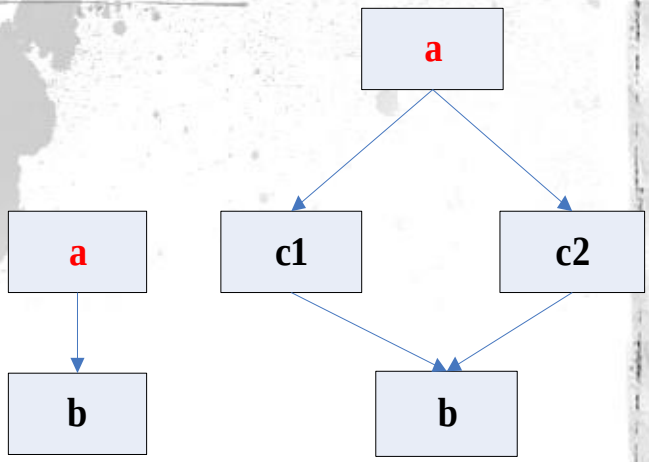
- What is loop?
  - Have a unique entry node, all the path from outside to inside, must pass the entry.
  - Nodes in this loops is strongly connected. Strong connection means that starting from one node, we can reach any other node (especially, when the set of nodes contains one node, it must have the directed edge to itself).



Not loop

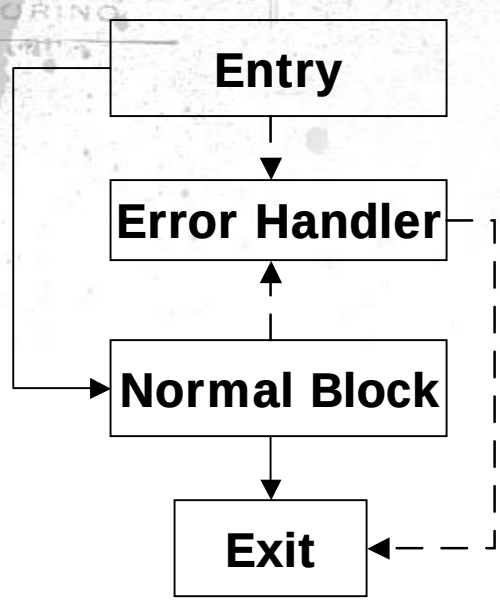
Dominator

- Definition
  - We say that b dominates a if every possible execution path from entry to a includes b.
- Two approaches to compute the set of the dominators:
  - a dominates b if and only if a=b, or a is the unique immediate predecessor of b, or b has more than one immediate predecessor and for all immediate predecessors c of b, c not a and a dominates c.
  - Lengauer and Tarjan's algorithm, faster but more complicated.



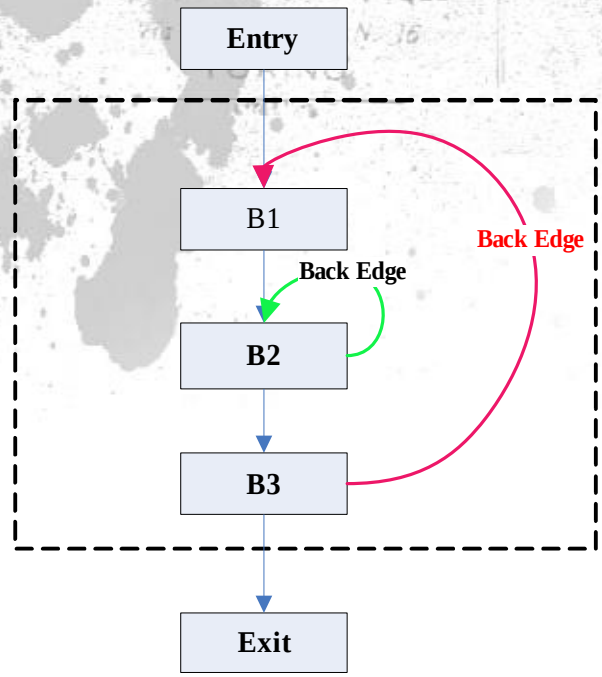
The possible problem during the determination of basic blocks

- C Language's Exception Mechanism
  - The call to setjmp will become the header of a new block.
  - Windows exception handler instruction



Back edge and Algorithm of loop detection

- Back edge in a flowgragh as one whose head dominates its tail.
- Given a back edge n **à** d, the loop of n **à** d is the subgraph consisting of the set of nodes containing d and all the nodes from which n can be reached in the flowgraph without passing through d and the edge set connecting all the nodes in its node set. Node d is the unique entry.



最大强连通图

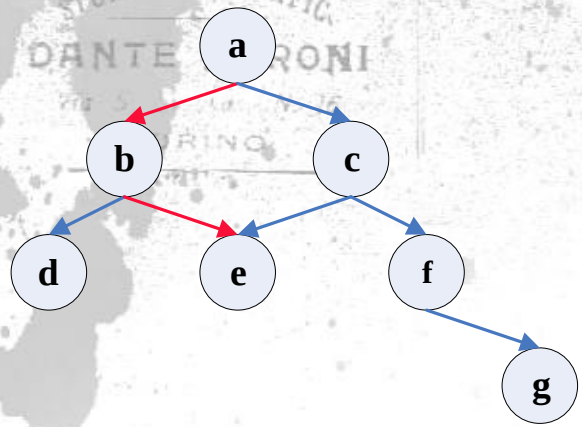
The demand for the data flow analysis

- Intra-procedure analysis
  - Locate the suspicious spots
  - Contain:
    - Basic Block analysis
    - U-D chain
    - Structure analysis
- inter-procedure analysis
  - Vuls always produced by several functions interaction.
  - The formation process of the buffer some times is not easy to judge.

➡ Use the both to get better effect.

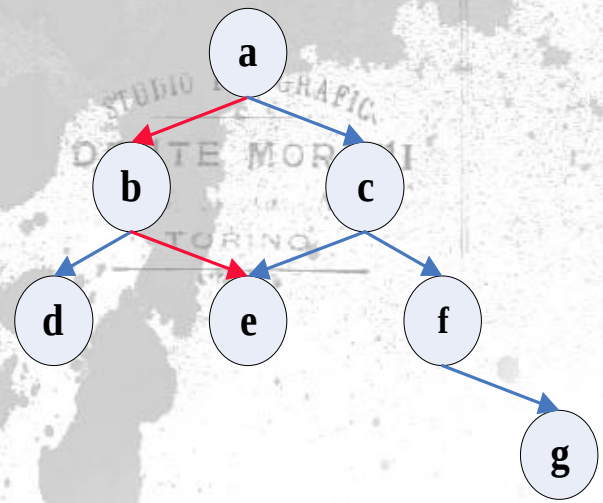
The demand for the inter-procedure analysis（1）

- Variable’s value?
- If function e is vulnerable.
- When error occurs, the exec path is
  - a->b->e
- We often meet the question?
  - When will function a branch b?
  - In point Y, when the value in reg X will be equal to Z?



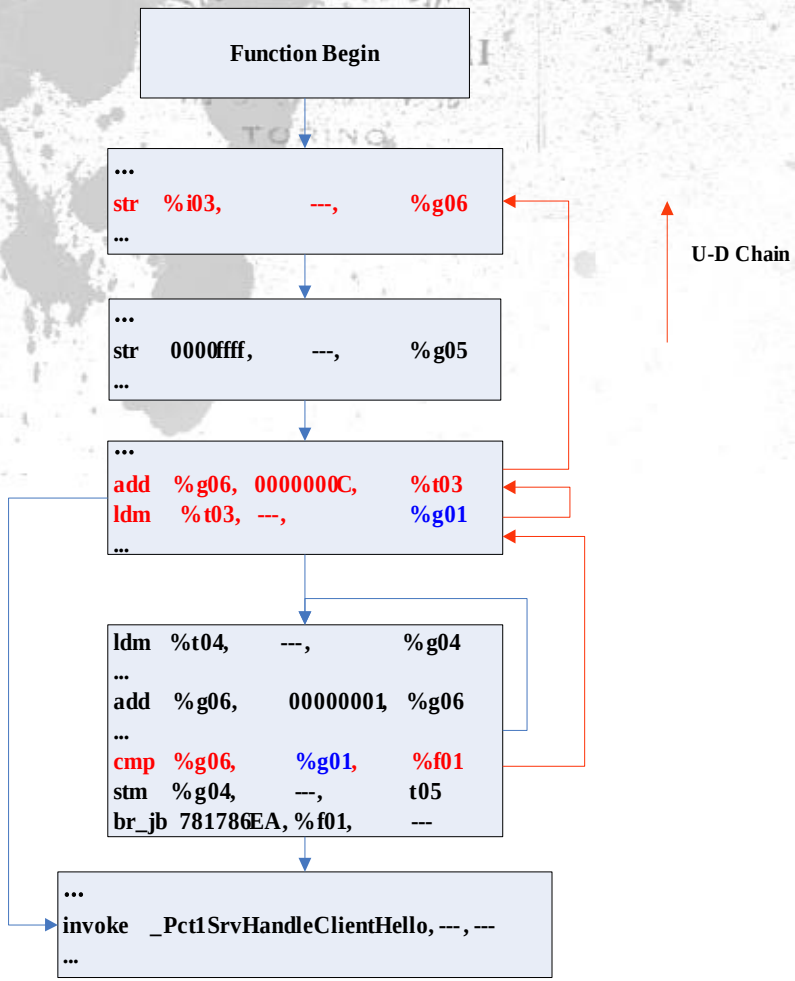
The demand for the Inter-procedure analysis（2）

- The construction of the data
- If bof may occur in e, we should check:
  - length of the buffer in b have been defined or compared for limitation?
  - Or comparison occurs in a?
  - The construction of buffer is very complicated, a, b and c take part in the data building.



Combine the Intra and Inter-Procedure analysis

- Combine the U-D chain analysis and I/O registers usage
- The complete data flow analysis must be the NP problem
- Use U-D chain analysis IIS PCT Vulnerability



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For advanced understanding, you should know

- Formal Language
- Formal Semantic, especially operation semantic
- Graph Theory
- Discrete Mathmatics
- Type Theory
- Compiler design and implementation
- Program anlaysis

The End

- Thank u!
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