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TruLogic
Trustable Logic Circuit Design

Hardware IP Classification through Weighted Characteristics

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Introduction

- **Today's integrated circuit (IC) industry**
  - **Economically oriented**
  - **Heavily reliant on incorporation of third-party intellectual property (IP)**
  - **Todays ICs are becoming more and more susceptible to attacks**
  - **Increased security threat**
  - **Increased threat of Trojan insertion**

Hardware Trojan

What is a Hardware Trojan?

- Malicious addition or modification of the circuitry of an integrated circuit
- Inserted Trojans can be very small
- Created by human intelligence
- Consequences that can come from Trojan not being detected:
  - Damaging payloads
  - Leaking secret keys
  - Shutting down sections of hardware
- Can end up in locations where security is vital

Previous Work Towards Detecting Trojans

- **Side-Channel Analysis**
  - Look at naturally occurring emissions
    - Power/timing delays
  - Detect modifications in a circuit by analyzing differences in power/delay
- **Path Delay**
  - Measure differences in how long a signal takes to travel through a specific path
  - Detect modifications in circuits by analyzing differences in delays

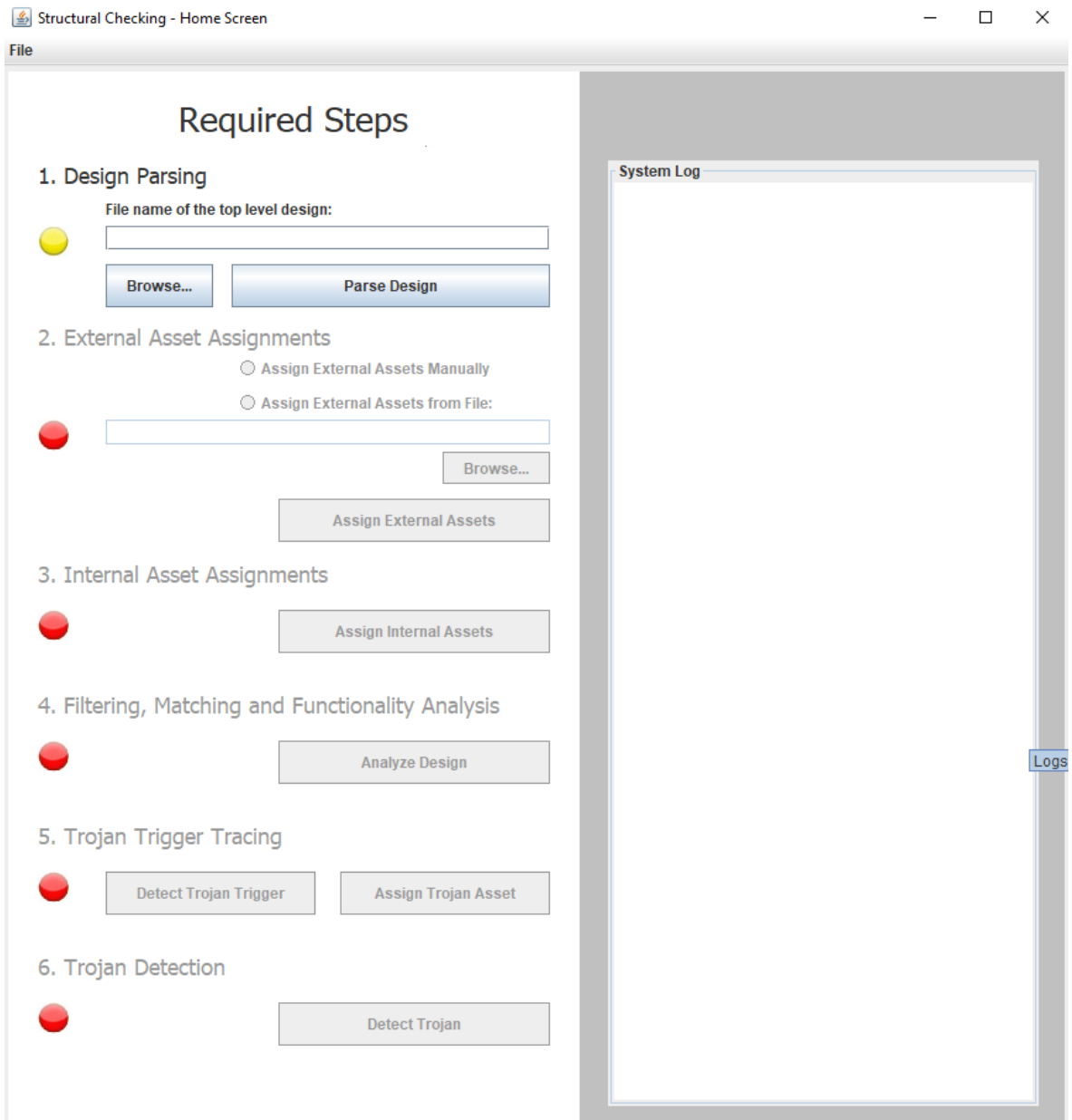
Limitations

- **While both Side-Channel Analysis and Path Delay are viable detection methods, they have their own limitations**
  - **Trojans can be very small**
    - **Do not produce significant emissions**
  - **Mainly focused on detecting Trojans on hard IPs and fabricated chips**

Our Approach

- **Structural Checking (SC)**
  - Analyze Register-Transfer Level (RTL) soft IPs
  - Assign assets to design and create asset patterns
  - Static analysis - no simulation required
  - Designed to be fast and thorough
  - Improved statistical analysis to enhance Trojan detection

Structural Checking Tool GUI



Assets

- **Provide labels to a signal about its purpose/function to the overall IP**
  - **Ex. clock signal would be assigned 'SYSTEM_TIMING' asset**
  - **A signal may have multiple assets**
    - **Help refine how the signal fits within overall design**
  - **There are two main categories of assets within SC tool**
    - **External assets**
    - **Internal assets**

External Assets

- **Used to describe the function/purpose of primary ports of a soft IP**
  - **Must be manually assigned upon first use (only user knows how the IP will be connected to the system)**
  - **Five main categories:**
    - **Data**
    - **Timing**
    - **System Control**
    - **Specific System Control**
    - **Miscellaneous**
  - **The SC tool currently has 58 external assets available**

External Asset Examples

- **Data**
  - DATA_MEMORY: signal that transfers data to or from any type of memory
- **Timing**
  - COUNT: signal that keeps track of a count value
- **System Control**
  - HANDSHAKING: handles any type of handshaking operations
- **Specific System Control**
  - COMMUNICATION_CONTROL: transmission with another component
- **Miscellaneous**
  - ADDRESS_SENSITIVE: connect to memory address of an IP

Internal Assets

- **Intended to describe function of internal signals within a soft IP**
  - **Can also be used for primary port signals**
  - **Most internal assets assigned automatically after SC tool parses the RTL code**
  - **A few assets that deal with scan chains need to be manually assigned**
  - **Examples of internal assets:**
    - **PROCESS_SENSITIVE: signal included in sensitivity list of a process block**
    - **CONDTIONAL_DRIVEN: signal within an “if/case” block**

Asset Filtering

- Allow assets assigned on any primary port signal to propagate through connected signals
  - A set of rules determines whether an asset is copied to its neighbor
  - Create traces for every signal path
- Asset Pattern – compilation of all asset traces of a soft IP
  - Broken down into six characteristics
  - Ex. Characteristic: external assets for primary input port signals

Golden Reference Library (GRL)

- Collection of soft IPs acquired from Trust-Hub, OpenCores, etc., categorized into various functionality groups
- GRL entries are labeled as:
  - Known Trojan-Free (whitelist)
  - Known Trojan-Infested (blacklist)

GRL Example

```
Entity    simple_pic:
    »»    33 port signals
    »»    60 IntraSignals
    »»    4 Port Signal Vectors
    »»    7 Intra-Signal Vectors
    »»    0 SubInstances
    »»    9 Processes
Functionality: INTERRUPT_UNIT
Secondary Func: NON_SEQUENTIAL
Number of Input bits:»  23
Number of Output bits:» 10
>[SYSTEM_TIMING]
>*[PROCESS_SENSITIVE, CONDITIONAL_DRIVING]
>[RESET]
>[INTERRUPT_CONTROL, HANDSHAKING]
>[ADDRESS_SENSITIVE]
>*[CONDITIONAL_DRIVING]
>[INTERRUPT_CONTROL]
>[DATA_SENSITIVE]
>[DATA_SENSITIVE, INTERRUPT]
<[DATA_SENSITIVE, INTERRUPT]
<*[CONDITIONAL_DRIVEN]
<[HANDSHAKING, INTERRUPT_CONTROL]
<*[CONCURRENT_DRIVEN]
<[INTERRUPT, DATA_SENSITIVE]
<*[CONDITIONAL_DRIVEN, PROCESS_OPERATION_SENSITIVE]
>[INTERRUPT, DATA_SENSITIVE]
/[DATA_SENSITIVE]
/*[CONDITIONAL_DRIVEN, PROCESS_OPERATION_SENSITIVE]
/[DATA_SENSITIVE, INTERRUPT]
/*[CONDITIONAL_DRIVEN]
/[HANDSHAKING, INTERRUPT_CONTROL]
/*[CONCURRENT_DRIVEN, CC_OPERATION_AND]
/[INTERRUPT_CONTROL]
/*[CONDITIONAL_DRIVING, CONCURRENT_DRIVEN, CC_OPERATION_AND]
```

Golden Reference Matching

- **Compare unknown soft IP asset pattern against an asset pattern within the GRL**
  - **Algorithm calculates percent match for each GRL entry**
    - **Determine overall functionality of design**
    - **Algorithm chooses best match for soft IP**
- **Basic matching example**

Trace	Unknown IP Assets	GRL Entry Assets	Percent Match
1	DATA_COMMUNICATION	DATA_COMMUNICATION	100%
2	DATA_SENSITIVE, COUNT, STATUS	DATA_SENSITIVE, HANDSHAKING, MEMORY_OP	33%
3	DATA_SENSITIVE	DATA_MEMORY	0%

Statistical Weight

- Overall match calculated by averaging the six percent matches from the six characteristics that make up asset patterns

$$\text{Overall \% Match} = \frac{\sum_{i=A}^{F} \%Match_i}{6}$$

  - Drawback – characteristics do not contribute equal weight
- To improve the algorithm we focus on:
  - Assessing Asset Quantity
  - Assessing Asset Quality

Formulas to Improve Algorithm

- Calculating weight of a given characteristic:

$$P(Asset) = \frac{\sum_{i=1}^{n} GRLEntry_i.contains(Asset)}{Total\ \#\ of\ GRL\ Entires}$$

$$Weight_{Asset} = 1 - P(Asset)$$

$$Average\ Asset\ Weight = \frac{\sum_{i=1}^{n} MatchedAsset_i.weight}{Total\ \#\ Matched\ Assets}$$

- Finally we can calculate the new characteristic weight by combining the formulas from above

$$Weight_{char} = \frac{Characteristic_{char}AverageAssetWeight}{\sum_{i=A}^{F} Characteristic_i AverageAssetWeight} * 100$$

Results

- **Tested IPs include RS232, RSA, AES, and a few microcontrollers**
  - **Statistical algorithm help extract important asset matches**
- **Examples of smaller designs:**
  - **RS232**
    - **Contain denial-of-service attack.**
    - **Both original and improved algorithm correctly match**
  - **AES**
    - **Contain secret key after certain plaintext is read**
    - **Both original and improved algorithm correctly match**

Results (cont.)

- **PIC16F84 – microcontroller obtained from Trust-Hub**
  - **Demonstrated improvement in statistical matching**
  - **Made up of:**
    - **Two types of memory EEPROM and RAM**
    - **Watchdog timer,**
    - **Interrupt ports,**
    - **I/O ports**

Results (cont.)

Asset Assignment

After parsing PIC16F84, assets are assigned to input and output ports

Signal	Assets
clk_i	SYSTEM_TIMING
clk_o	SYSTEM_TIMING
eep_adr_o	ADDRESS_SENSITIVE
eep_dat_i	DATA_MEMORY
eep_dat_o	DATA_MEMORY
existeprom_i	MEMORY_OP
int0_i	INTERRUPT
int4_i	INTERRUPT
int5_i	INTERRUPT
int6_i	INTERRUPT
int7_i	INTERRUPT
mclr_n_i	RESET
pon_rst_n_i	RESET
porta_dir_o	PERIPHERAL_CONTROL
porta_i	DATA_PERIPHERAL
porta_o	DATA_PERIPHERAL
portb_dir_o	PERIPHERAL_CONTROL
portb_i	DATA_PERIPHERAL
portb_o	DATA_PERIPHERAL
powerdown_o	CLOCK_CONTROL
prog_adr_o	ADDRESS_SENSITIVE
prog_dat_i	DATA_MEMORY
ram_adr_o	ADDRESS_SENSITIVE

Results (cont.)

Basic Matching

GRL Entry	Overall Percent Match
Simple_pic	52.553%
Lcd16x2_ctrl	48.233%
Lcd_controller	44.148%
RSACypher_T100	43.414%
Spi_master_1	40.750%

Improved Matching

GRL Entry	Overall Percent Match
Simple_pic	47.149%
Lcd16x2_ctrl	36.591%
Lcd_controller	36.514%
RSACypher_T100	31.785%
Spi_master_1	30.211%

Basic Matching vs. Improved Matching

- After asset assignment, SC tool filters assets to connected signals
- Better matching due to disparity between overall percent match of GRL entries

Results (cont.)

- **MC8051-T500 Core – tested microcontroller known to be Trojan-free**
  - **Also demonstrated improvement in statistical matching**
  - **Made up of:**
    - **Control units for Finite State Machine (FSM) and memory**
    - **ALU**
    - **Serial Interface Unit (SIU)**
    - **Timing Unit**
      - **Also handle interrupt signals**

MC8051-T500 Core Matching Results

	Equal Weight Matching		Statistical Based Matching	
Target IP	Functionality	% Match	Functionality	% Match
MC8051_core	COMMUNICATION	35.321%	INTERRUPT_UNIT	50.899%
MC8051_control	COMPUTATIONAL	44.871%	REGISTER_FILE	54.689%
Control_fsm	COMPUTATIONAL	47.767%	REGISTER_FILE	38.913%
Control_mem	INTERRUPT_UNIT	61.576%	INTERRUPT_UNIT	62.274%
MC8051_alu	COMPUTATIONAL	22.244%	COMPUTATIONAL	29.564%
Alumux	COMPUTATIONAL	55.565%	COMPUTATIONAL	46.519%
Alucore	COMPUTATIONAL	50.297%	COMPUTATIONAL	42.133%
Addsub_core	COMPUTATIONAL	44.250%	COMPUTATIONAL	41.169%
Addsub_cy	COMPUTATIONAL	46.875%	COMPUTATIONAL	44.748%
Addsub_ovcy	COMPUTATIONAL	46.875%	COMPUTATIONAL	44.748%
Comb_mltplr	COMPUTATIONAL	45.833%	COMPUTATIONAL	38.863%
Comb_divider	COMPUTATIONAL	37.500%	COMPUTATIONAL	35.399%
Dcml_adjust	COMPUTATIONAL	31.718%	COMPUTATIONAL	34.492%
MC8051_siu	COMMUNICATION	77.152%	COMMUNICATION	70.793%
MC8051_tmrctr	REGISTER_FILE	52.257%	INTERRUPT_UNIT	48.587%

Conclusion

- **The statistical matching algorithm**
  - **Enhanced matching algorithm for SC tool**
  - **Calculate weights for individual assets**
    - **Tool determines how well an asset matches to a soft IP**
  - **Using weights helps facilitate numerical representation of the six characteristic**
  - **Helps provide a more unique identification for targeted IPs**

Future Work

- In order to improve the SC tool we intend to:
  - Continually grow the GRL to improve matching
  - Add more assets in order to better refine the purpose of each signal within an IP
  - Add more functionalities within GRL to provide more options to classify an unknown IP