APPENDIX

Table 1. **Context-free properties extracted from existing CVEs, relevant protocol software RFCs, GitHub issues, and an understanding of program implementations. Note: A *match* indicates that program behavior which satisfies the specified property constitutes a bug, whereas a *fail* denotes that program behavior violating the property is considered a bug.**

Prop	Program	Description of the context-free property
LN1	`luna`(0.1.1)	$S \rightarrow A\ S\ B \mid B\ S\ A \mid S\ S \mid \epsilon$ **(fail)** The number of calls to the **A**(`scan_string()`) function is **not equal to** the number of **B**(`buf_assignment`) operations.
LN2	`luna`(0.1.1)	$S \rightarrow Q\ B \mid S\ B \mid S\ S$ $Q \rightarrow A\ Q\ B \mid B\ Q\ A \mid Q\ Q \mid \epsilon$ **(match)** The number of times **A**(`Selfexpr_notnull`) is **fewer than** the number of calls to the **B**(`visit_unary_op()`) function.
LN3	`luna`(0.1.1)	$S \rightarrow Q\ P \mid S\ P \mid S\ S$ $P \rightarrow B\ \mid C$ $Q \rightarrow A\ Q\ P \mid P\ Q\ A \mid Q\ Q \mid \epsilon$ **(match)** The number of occurrences of the **A**(`RK_Cnot0`) event is **fewer than** the combined number of occurrences of the **B**(`LUNA_OP_MOD`) and **C**(`LUNA_OP_DIV`) events.
MJ1	`mujs`(1.0.6)	$S \rightarrow Q\ B \mid S\ B \mid S\ S$ $Q \rightarrow A\ Q\ B \mid B\ Q\ A \mid Q\ Q \mid \epsilon$ **(match)** The number of calls to the **A**(`js_error()`) function is **less than** the number of occurrences of the **B**(`js_regexec_less0`) event.
MJ2	`mujs`(1.0.6)	$S \rightarrow Q\ B \mid S\ B \mid S\ S$ $Q \rightarrow A\ Q\ B \mid B\ Q\ A \mid Q\ Q \mid \epsilon$ **(match)** The number of calls to the **A**(`die_overflow()`) function is **less than** the number of occurrences of the **B**(`g_yymin_yymaxREPINF`) event.
MJ3	`mujs`(1.0.8)	$S \rightarrow Q\ B \mid S\ B \mid S\ S$ $Q \rightarrow A\ Q\ B \mid B\ Q\ A \mid Q\ Q \mid \epsilon$ **(match)** The number of calls to the **A**(`die_sequence()`) function is **less than** the number of occurrences of the **B**(`missing_end_of_string`) event.
MJ4	`mujs`(1.0.9)	$S \rightarrow Q\ B \mid S\ B \mid S\ S$ $Q \rightarrow A\ Q\ B \mid B\ Q\ A \mid Q\ Q \mid \epsilon$ **(match)** The number of calls to the **A**(`jsG_markobject()`) function is **less than** the number of occurrences of the **B**(`obj_gcmark_notmark`) event.
MJ5	`mujs`(1.0.9)	$S \rightarrow A\ S\ B \mid B\ S\ A \mid S\ S \mid \epsilon$ **(fail)** The number of calls to the **A**(`jsR_run()`) function is **not equal to** the number of occurrences of the **B**(`OP_RETURN`) event.
LV1	`Live555`(0.78)	$S \rightarrow Q\ P \mid S\ P \mid S\ S$ $P \rightarrow B\ C$ $Q \rightarrow A\ Q\ P \mid P\ Q\ A \mid Q\ Q \mid \epsilon$ **(match)**

		The number of times the server `rejects and returns a` **A**(`NotAllowed response`) is **less than** the number of occurrences of the series of events where the server `establishes` a **B**(`connection`) with the client and then `receives an` **C**(`illegal request`)
LV2	`Live555`(0.92)	$S \rightarrow A\,Q \mid A\,S \mid S\,S$ $Q \rightarrow A\,Q\,B \mid B\,Q\,A \mid Q\,Q \mid \epsilon$ **(match)** The number of occurrences of the **A**(`Startplay`) event is **greater than** the number of occurrences of the **B**(`Ready_Playrequest`) event.
LV3	`Live555`(0.92)	$S \rightarrow A\,Q \mid A\,S \mid S\,S$ $Q \rightarrow A\,Q\,B \mid B\,Q\,A \mid Q\,Q \mid \epsilon$ **(match)** After establishing the connection, the number of times the first valid **A**(`setup request`) is received is **greater than** the number of times a **B**(`valid MediaSource`) is created.
LV4	`Live555`(0.92)	$S \rightarrow Q\,B \mid S\,B \mid S\,S$ $Q \rightarrow A\,Q\,B \mid B\,Q\,A \mid Q\,Q \mid \epsilon$ **(match)** After establishing the connection, the number of **A**(`valid MediaTable entries`) is **fewer than** the number of **B**(`valid setup requests`).
TD1	`TinyDTLS`(0.9-rcl)	$S \rightarrow P\,Q\,C \mid C\,Q\,P \mid Q\,Q \mid \epsilon$ **(fail)** $P \rightarrow A\,B$ The number of occurrences of the sequence of **A**(`wait_clienthello`) and **B**(`clientvalidhello`) events is **not equal** to the number of occurrences of the **C**(`serverhello`) event.
TD2	`TinyDTLS`(0.9-rcl)	$S \rightarrow A\,S\,B \mid B\,S\,A \mid S\,S \mid \epsilon$ **(fail)** The number of occurrences of the **A**(`checkcertificate`) event is **not equal** to the number of occurrences of the **B**(`Alertresponse`) event
TD3	`TinyDTLS`(0.9-rcl)	$S \rightarrow P\,C \mid S\,C \mid S\,S$ $P \rightarrow A\,B$ $Q \rightarrow P\,Q\,C \mid C\,Q\,P \mid Q\,Q \mid \epsilon$ **(match)** The number of occurrences of the sequence of **B**(`wait_clienthello`) and **B**(`hellowithinvalidcookie`) events is **greater than** the number of occurrences of the **B**(`helloverify`) event.
TD4	`TinyDTLS`(0.9-rcl)	$S \rightarrow Q\,P \mid S\,P \mid S\,S$ $P \rightarrow B\,C$ $Q \rightarrow A\,Q\,P \mid P\,Q\,A \mid Q\,Q \mid \epsilon$ **(match)** The number of times the server rejects and **B**(`sends an Alert`) is **fewer than** the number of occurrences of the sequence where the server receives a **B**(`ClientHello`), gives a **B**(`HelloVerifyRequest`) response, and then receives an `over-large packet`.
EV1	`Exiv2`(0.27.6)	$S \rightarrow Q\,B \mid S\,B \mid S\,S$ $Q \rightarrow A\,Q\,B \mid B\,Q\,A \mid Q\,Q \mid \epsilon$ **(match)**

		The number of occurrences of the **A**(`err_return`) event is **less than** the number of occurrences of the **B**(`total_out_of_bounds`) event.
OS1	`OpenSSL(1.0.2)`	$S \rightarrow Q\ A\ C$ $Q \rightarrow A\ Q\ B \mid B\ Q\ A \mid Q\ Q \mid Q\ A \mid A\ Q \mid \epsilon$ **(match)** The number of occurrences of the **A**(`Sig_A`) event is **greater than** the number of occurrences of the **B**(`Slen_A`) event, and it concludes with the sequence of `Sig_A` followed by **C**(`Slen_U`) events.
OS2	`OpenSSL(1.1.0)`	$S \rightarrow Q\ B \mid S\ B \mid S\ S$ $Q \rightarrow A\ Q\ B \mid B\ Q\ A \mid Q\ Q \mid \epsilon$ **(match)** The number of calls to the **A**(`SSLerr()`) function is **less than** the number of occurrences of the **B**(`ssl_generate_pkey_isnull`) event.
OS3	`OpenSSL(1.1.1)`	$S \rightarrow Q\ A\ C$ $Q \rightarrow A\ Q\ B \mid B\ Q\ A \mid Q\ Q \mid Q\ A \mid A\ Q \mid \epsilon$ **(match)** The number of occurrences of the **A**(`Tmpsig_A`) event is **greater than** the number of occurrences of the **B**(`Tmpslen_A`) event, and it concludes with the sequence of `Tmpsig_A` followed by **C**(`Tmpslen_U`) events.