TCT: General Information

TCT is a program for the synthesis of supervisory controls for discrete-event systems. Generators and recognizers are represented as standard DES in the form of a 5-tuple

[Size, Init, Mark, Voc, Tran]

Size is the number of states (the standard state set is {0, …, Size−1}), Init is the initial state (always taken to be 0), Mark lists the marker states, Voc the vocal states, and Tran the transitions. A vocal state is a pair [*I*, *V*] representing positive integer output *V* at state *I*. A transition is a triple [*I*, *E*, *J*] representing a transition from the exit (source) state *I* to the entrance (target) state *J* and having event label *E*. *E* is an odd or even nonnegative integer, depending on whether the corresponding event is controllable or uncontrollable.
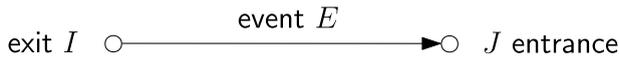
All DES transition structures must be deterministic: distinct transitions from the same exit state must carry distinct labels.

Synthesis Procedures

DES = **create**(DES)

> is a new discrete-event system (DES). Option 1 allows fast user input via a sequence of prompts, resulting in direct creation of a .DES file. Option 2 allows the user to create a text (.ADS) file with any ASCII text editor; this file can be converted to a .DES file using the *TCT* procedure **FD**.

DES2 = **selfloop**(DES1,[SELF-LOOPED EVENTS])

> is DES1 augmented by a selfloop (q, E, q) for each listed event E, at each state q where a transition (q, E, q') is not already defined. The event E can be chosen freely and need not belong to the alphabet of DES1.

DES2 = **trim**(DES1)

> is the trim (reachable and coreachable) substructure of DES1.

DES = **sync**(DES1,DES2,…,DESk)

> is the (reachable) synchronous product of DES1,DES2,…,DESk. DES need not be coreachable. Not for use with vocalized DES.

DES = **meet**(DES1,DES2,…,DESk)

> is the meet (reachable cartesian product) of DES1,DES2,…,DESk. DES need not be coreachable. Not for use with vocalized DES.

DES3 = **supcon**(DES1,DES2)

> is a trim generator for the supremal controllable sublanguage of the marked legal language generated by DES2 with respect to the plant DES1. DES3 provides a proper supervisor for DES1. Not for use with vocalized DES.

DES2 = **force**(DES1,[FORCIBLE EVENTS],[PREEMPTIBLE EVENTS], TIMEOUT EVENT)

> is DES1 modified by the insertion of a new timeout event whose disablement forces an event in the forcible list to preempt every event in the preemptible list. Not for use with vocalized DES.

DES3 = **mutex**(DES1,DES2,[EXCLUDED-STATE-PAIRS])

> is formed from the product of DES1 and DES2, by excluding state pairs listed as [[I1,J1],[I2,J2],…], plus all state pairs from which they are reachable along an uncontrollable path; and then taking the reachable substructure of the result. DES3 is reachable and controllable, but need not be coreachable. For the corresponding control data, compute DES = **sync** (DES1,DES2), then DAT = **condat**(DES,DES3). If DES3 is trim, it provides a proper supervisor for the mutual exclusion problem; if not, a solution is SUP = **supcon**(DES,DES3). Not for use with vocalized DES.

DAT2 = **condat**(DES1,DES2)

> returns control data DAT2 for the supervisor DES2 of the controlled system DES1. If DES2 represents a controllable language (with respect to DES1), as when DES2 has been previously computed with **supcon**, then DAT2 will tabulate the events that are to be disabled at each state of DES2. In general **condat** can be used to test whether the language represented by DES2 is controllable with respect to DES1: just check that the disabled events tabled in DAT2 are themselves controllable (have

odd-numbered labels). To show DAT call **SA**. Not for use with vocalized DES.

DES3 = **supreduce**(DES1,DES2,DAT2)

is a reduced supervisor for plant DES1 which is control-equivalent to DES2, where DES2 and control data DAT2 were previously computed using **supcon** and **condat**. Also returned is an estimated lower bound slb for the state size of a strictly state-minimal reduced supervisor. DES3 is strictly minimal if its reported state size happens to equal the slb.

{LOC1,LOC2,…,LOCm} = **localize**(PLANT,{PLANT1,…,PLANTm},SUPER)

is the set of localizations of SUPER to the *m* independent components PLANT1,…,PLANTm of PLANT. Independence means that the alphabets of PLANT1,…,PLANTm must be pairwise disjoint. Optionally, correctness of localization is verified and reported as ControlEqu(…) in MAKEIT.TXT. **localize** is mainly for use when SUPER is a decentralized supervisor with authority over PLANT1,…,PLANTm, and PLANT is their synchronous product. Not for use with vocalized DES.

DES2 = **minstate**(DES1)

is a minimal-state DES that generates the same closed and marked languages as DES1, and the same string mapping induced by vocalization (if any). DES2 is reachable, but not coreachable unless DES1 is coreachable.

DES2 = **complement**(DES1, [AUXILIARY-EVENTS])

is a generator of the marked language complementary to the marked language of DES1, with respect to the extended alphabet comprising the event labels of DES1 plus those in the auxiliary-event list. The closed behavior of DES2 is all strings over the extended alphabet. The string mapping induced by vocalization (if any) is unchanged.

DES2 = **project**(DES1, [NULL/IMAGE EVENTS])

is a generator of the projected closed and marked languages of DES1, under the natural projection specified by the listed NULL or IMAGE events. In decentralized control, DES2 could be an observer's local model of DES1. Not for use with vocalized DES.

DES2 = **relabel**(DES1, [OLD-NEW EVENT LABEL PAIRS])

is a generator for the relabeled closed and marked behaviors of DES1, where the relabeling of languages maps each listed DES1 event label (alphabet element) into a specified label of DES2; unlisted DES1 labels are unchanged, while some DES2 labels may coincide with unlisted DES1 labels. Not for use with vocalized DES.

DES2 = **vocalize**(DES1, [STATE-OUTPUT PAIRS])

>   has the same closed and marked behaviors as DES1, but with user-selected state output at the entrance state corresponding to each selected (exit state, event input) pair.

DES2 = **outconsis**(DES1)

>   has the same closed and marked behaviors as DES1, but is output-consistent in the sense that nonzero state outputs are unambiguously controllable or uncontrollable. A vocal state with output V in the range 10,…,99 may be split into siblings with outputs, respectively, V1 or V0 in the range 100,…,991.

DES2 = **hiconsis**(DES1)

>   has the same closed and marked behaviors as DES1, but is hierarchically consistent in the sense that high-level controllable events may be disabled without side effects. This may require additional vocalization together with changes in the control status of existing state outputs. **hiconsis** incorporates and extends **outconsis**.

DES2 = **higen**(DES1)

>   is defined over the state-output alphabet of (vocalized) DES1 and represents the closed and marked state-output (or 'high-level') behaviors of DES1. For instance, starting with a 'low-level' vocalized model GLO, the sequence

$$OCGLO = \textbf{outconsis}(GLO)$$
$$HCGLO = \textbf{hiconsis}(OCGLO)$$
$$HCGHI = \textbf{higen}(HCGLO)$$

>   returns a DES pair (HCGLO, HCGHI) that is hierarchically consistent: controllable languages in HCGHI can be synthesized, via the state-output map, as controllable languages in HCGLO.

DES3 = **supnorm**(DES1,DES2,[NULL/IMAGE EVENTS])

>   is a trim DES which represents the supremal sublanguage of the legal language represented by DES2, that is normal with respect to the marked behavior of the plant generator DES1 and the natural projection specified by the NULL/IMAGE event list. Not for use with vocalized DES.

DES3 = **supscop**(DES1,DES2,[NULL/IMAGE EVENTS])

>   is a trim DES which represents the supremal normal solution to the Supervisory Control and Observation Problem (SCOP), corresponding to the plant DES1, legal language DES2, and specified natural projection. In this solution, only observable controllable events may be disabled. Not for use with vocalized DES.

DES3 = **suprobs**(DES1,DES2,[NULL/IMAGE EVENTS])

is a trim DES which represents the supremal relatively observable sub-language of the language represented by DES2, with respect to the plant DES1, and specified natural projection. Not for use with vocalized DES.

DES3 = **supconrobs**(DES1,DES2,[NULL/IMAGE EVENTS])

is a trim DES which represents the supremal controllable and relatively observable sublanguage of the legal language represented by DES2, with respect to the plant DES1 and specified natural projection. In this solution, any controllable event, observable or not, is subject to disablement. Not for use with vocalized DES.

DES2 = **sup(s)qc**(DES1,[NULL/IMAGE EVENTS])

is a possibly nondeterministic DES with 'silent' transitions (labeled 'e') which represents DES1 reduced by canonical (i.e. supremal) (strong) quasi-congruence with respect to the specified natural projection. The user may select whether or not to print the corresponding state partition in MAKEIT.TXT; the printout omits singleton cells. Not for use with vocalized DES.

DES2 = **allevents**(DES1)

is a marked one-state DES self-looped with all the events of DES1. DES2 can be used as specification for the supervisory control of DES1 with respect to the sole criterion of nonblocking.

(DES3,DES4) = **natobs**(DES1,DES2)

returns a natural projection DES3 of DES1, where the projection is a natural observer, for the marked behavior of DES1, with (**allevents**) image representation DES4. The event list of DES4 is an economical extension of the Seed event list supplied by the user in the form of an **allevents** representation DES2. For **natobs** to be valid DES1 should be trim.

DES2 = **uncertmod**(DES1,[NULL/IMAGE EVENTS])

returns the uncertainty model of DES1 obtained by projection modulo uncertainty sets, corresponding to the specified natural projection on strings.

true/false = **nonconflict**(DES1,DES2)

tests whether DES1, DES2 are nonconflicting, namely whether all reachable states of the product DES are coreachable. Not for use with vocalized DES.

true/false = **isomorph**(DES1,DES2)

tests whether DES1 and DES2 are identical up to renumbering of states (but with initial state held fixed at 0); if so, their state correspondence can be displayed.

true/false = **(s)observ**(DES1,DES2,[NULL/IMAGE EVENTS])

> tests whether the language represented by DES2 is (strongly) (DES1,P)-observable, for the specified natural projection P. If observability fails, a diagnostic is provided with state(s) and event(s) where failure occurs. Not for use with vocalized DES.

Utilities

DES2 = **BFS**(DES1)

> is DES1 with its state set recoded by breadth-first search from state 0. BFS recoding can facilitate drawing a transition diagram, or in compensating for previous recodings introduced by **outconsis** or **hiconsis**.

DES2 = **edit**(DES1)

> is obtained from DES1 by user-selected modifications.

ScreenDisplay = **show**(DES)

> **SE** displays an existing DES, **SA** a DAT (**condat**) table, **SX** a TXT (text) file. Tables can be browsed with page keys. The file MAKEIT.TXT keeps a record of user files as they are generated.

TextFile = **FE**(DES)/**FA**(DAT)

> is an ASCII text file PDS/PDT for printing or offline conversion to another format.

DESFile = **FD**(ADS)

> converts an ADS file or group of files, formed using **create** (option 2), to the corresponding DES file(s).

UserDirectory = **UD**

> is a listing of the current user subdirectory.

GIF = **CE**(DES)

> converts a DES file to a GIF file for graphical display.

LabeledTransitionGraph = **DE**(GIF)

> displays a GIF file obtained from **CE**, as a labeled transition graph; marker states are denoted by a double circle.